A REVIEW

of the

LITERATURE

on

SOIL INSECTICIDES

By

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LONDON:
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1945

FOREWORD.

The Conference on Insecticides and Fungicides of the Agricultural Research Council of the United Kingdom decided to ask Dr. H. C. Gough, Ph.D., of the Advisory Department of Leeds University, to prepare a Review of the Literature on Soil Insecticides. The subject is one of wide interest and of great economic importance, on which information is scattered. As, also, contradictory results have been recorded for almost all substances tried, the need for careful control of experiments and analysis of the results is clear. For all these reasons the wide circulation of a review of existing information is desirable. With this object, the Agricultural Research Council has kindly given Dr. Gough's review to the Imperial Institute of Entomology for publication.

As explained in the author's introduction, the period covered by this work begins with 1914, and though it contains some references subsequent to 1940, it is reasonably complete only up to that date. Owing to war conditions, there has thus been an unavoidable interval between the preparation and issue of the work.

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September, 1945.

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INTRODUCTION.

The Problem of Soil Insects.

Many pests of crops attack the underground part of the plant concerned or use the soil as a place of refuge. Their control constitutes a problem which has engaged the attention of entomologists in all parts of the world and one which has never been satisfactorily solved. The problem may be approached in the following ways :—

(*a*) Cultural measures to increase the resistance of the crop to insect attack.

(*b*) Mechanical methods, such as soil cultivations, which not only disturb and kill many insects directly, but also expose them to birds and other natural enemies.

(*c*) Physical methods, such as steam sterilisation or flooding.

(*d*) Chemical methods, comprising the application of substances to kill insects in the soil and the use of chemicals to deter the insects from attacking the crop or depositing their eggs near it.

(*e*) Attracting the insects to baits, where they can be collected or destroyed by chemicals or other means.

(*f*) Attacking an aerial stage of the pest.

(*g*) Biological control, which has had a very limited application in the control of soil pests.

(*h*) Quarantine legislation.

All these methods are only special applications of the general principles of insect control and plant protection, and it is not proposed to consider them except to show the relationship that chemical control bears to the other methods. Theoretically, as Martin (1936) states, the application of a toxic chemical to the soil should be a far simpler matter than applying it to plant foliage. In practice, however, to find a substance which conforms to even a few of the requirements of the ideal soil insecticide is far from easy. These requirements are :—

(i) It should be toxic to insects.

(ii) It should not be toxic to plants at insecticidal rates or, if it is, the effect should not be long-lasting.

(iii) It should not permanently disturb the equilibrium of the soil micro-organisms, though some degree of toxicity to them appears to have a beneficial effect.

(iv) It should have good power of dispersal in the soil, and must therefore be a liquid or a solid of high volatility.

(v) The cost of the material and distribution should be well within the margin of profit of the crop concerned.

(vi) It should be easy to handle and apply.

(vii) It should not deteriorate during storage nor be inflammable.

(viii) It should not react directly with manures or fertilisers nor remove or lock up plant nutrients in the soil.

No known substance combines even most of these qualities. Most possible soil insecticides are toxic to plants at rates approaching those necessary to kill insects and are too expensive and uncertain in their action for agricultural use, though in nurseries and glasshouses, where the profit per acre is much higher and the area to be treated relatively small, comparatively expensive materials may have a useful application.

The search for suitable substances has been widespread and there can be few

applied entomologists in any part of the world who have not attempted some experiments with soil insecticides. The first recorded use of a soil insecticide on a large scale was the application of carbon disulphide to control the vine *Phylloxera* in France during the latter part of the last century, and this still remains the most widely used chemical.

Owing to the frequency with which negative results have been obtained and the difficulties inherent in the problem, a vast amount of work has probably gone unrecorded, and much has only been published in experiment station reports and other somewhat inaccessible periodicals. Many important papers give comparative results of a large number of different substances, some common insecticides, others apparently selected more or less at random. It was to correlate and integrate all this scattered work, so that the essentials of it should be readily accessible, that the present review was undertaken while the writer was working on soil insecticides at Rothamsted Experimental Station. The review was discontinued when the writer left to go to the Department of Agriculture, Leeds University, and taken up again at the request of the Agricultural Research Council.

Owing to the contradictory results obtained by different authors for almost all substances, the conclusions to be drawn from the review are rather meagre. That fact itself is, however, of great significance, and draws attention to the necessity of carefully controlled experiments and analyses of the factors which might affect the results.

The Scope of the Review.

In order to reduce the amount of material to be examined, certain limitations have been observed. Firstly, soil insecticides *in sensu stricto* are dealt with, and work on soil sterilisation which is particularly concerned with soil micro-organisms is excluded, though certain references to this subject are mentioned for the more important chemicals. The review also omits all reference to the control of Nematodes, a subject which is developing a literature of its own and which, although closely related to soil insecticides, was one which the writer did not feel competent to discuss. It does include, however, the control of Myriopods and Arachnids in the soil.

Although the review principally deals with the application of chemicals to the soil to kill insects, it is almost impossible, with the evidence available, to decide whether certain substances have acted as deterrents or insecticides. Thus, while it is highly probable that many substances applied for the control of the root flies of cabbage, onion and carrot act as deterrents to oviposition, the possibility that they act as ovicides or larvicides cannot be overlooked.

The control of soil insects by poison baits is also excluded, although for some soil pests this is the most suitable method of control. The application of poisons to insects previously attracted to baits is, however, dealt with.

Thus, within the scope of this review, a soil insecticide is defined as a chemical which is applied to the soil with the object of killing one or more stages of Arthropod pests. For the more common insecticides a certain amount of selection had to be exercised to keep the bulk of material within reasonable proportions. No useful purpose would have been served by listing, for example, all the numerous references on the use of corrosive sublimate for the control of cabbage root fly, and in general, references which did not give details of the amounts of chemical, and the area to which it was applied, have been omitted. Certain pests can only doubtfully be classified as soil insects. For example, Crambid larvae live rather at the bases of grasses than actually in the soil at the roots. These and some other similar insects have been included, as their control by insecticides presents a problem similar to that of the control of true soil insects.

Method of Abstracting.

The *Review of Applied Entomology* was used as a basis; every article in it was perused and references to soil insecticides noted. As an additional check,

references in the index to the more important soil insecticides were consulted. So far as possible the original papers were then consulted and the literature cited in these also examined where necessary. It is probable that some papers published prior to the first volume of the *R.A.E.* (1914) have been missed, but, apart from historical interest, the majority of these are not of great importance, and those which are would have been cited by later authors. The early reports of the more important world experiment stations were also scanned, and it is thought that little information of note has been overlooked. So far as possible, the earliest known users of the various substances have been mentioned, but this review does not pretend to have any value from the historical aspect, and it deals mainly with more recent work covering a wide range of insects, chemicals and places, and condensing such information as can be usefully summarised.

Arrangement.

The main part of the work has been arranged under chemicals, and within chemicals, under insects. For this latter purpose the normally accepted classification based on Imms (1934) has been adopted. The sub-orders, and in most cases the families, are given, and after that the most convenient arrangement is used. Under SCARABAEIDAE, for example, an entirely arbitrary classification has been adopted in order to bring together comparable data.

The more important chemicals which have already been used extensively as soil insecticides have been grouped together in the first section and are arranged alphabetically. The remaining substances, also arranged alphabetically, follow with cross-references where a substance has more than one name or is dealt with as a pure substance and as a crude product. Such substances as these are very difficult to classify ; usually the name employed by the original author has been used, though one author might describe a substance as a coal-tar product and another might describe the same substance as a crude carbolic acid. The foreign names for such products are also very confusing, the same or similar words having one significance in one language and a different one in another.

Where the data given by the original author are sufficient, the rate of application has always been reduced to grams per square metre (gm./sq. m.) to facilitate comparisons. Where a mixture of substances has been used, or the rate of application has been given for a diluted substance, the number of grams refers to the actual substance under discussion, except where otherwise stated, *e.g.* 10 gm. emulsion/sq. m. Often the original data are expressed as a measure of volume, but where the specific gravity is known the weight has been calculated. This conversion may not have been always accurate as specific gravities given in books of reference are for pure substances, and frequently impure forms are used as soil insecticides. Another difficulty has been that measurements of liquids are often given in ounces without stating whether fluid ounces or ounces avoirdupois are implied. It has been assumed in all such cases that fluid ounces are intended, and transformations have been made on that assumption. Where the specific gravity is not known, the results have been expressed as cubic centimetres per square metre (cc./sq. m.). Except when otherwise stated (*e.g.* U.S. gallons), imperial liquid measure is implied. To convert gm./sq. m. roughly into British units, divide by 30 for ounces/sq. yd. or multiply by 10 for lb./ac. For more exact transformations, data are given in Appendix 2. Such conversions have all been worked out on a slide rule and are not accurate to more than three places of decimals; they are only intended to serve as a rough guide. If sufficient information exists to make it worth while for a given chemical, the range over which it has been tested and the rates at which high kills have frequently resulted are given.

Such aspects as application, distribution and determination in the soil, effect on plants and micro-organisms are most conveniently dealt with separately for each chemical, or noted under individual references. A brief general account of each of these subjects is, however, given on pages 4–12 of this review.

The chemical data have been obtained from various sources. The formulae

and specific gravity are mainly taken from Hodgman and Lange (1927). More detailed information has been derived from text-books of organic chemistry (chiefly Cohen, 1923, and Schmidt, 1920) and also from text-books on insecticides by Martin (1936) and Shepard (1939).

Certain authors, notably Tattersfield and Roberts (1920) and Fleming (1925), have carried out experiments on a very large number of different substances, and to avoid repetition the details of these experiments are given here, so that it will only be necessary to give the relevant figures for each substance. In order not to lose the comparative value of the results, these are given completely in the Appendix.

Tattersfield and Roberts studied the effect of various chemicals on wireworms (*Agriotes* spp.). The insects were confined in air in conical flasks, usually of about one litre capacity and subjected to various amounts of the substance to be tested. The amount which resulted in death was recorded as the number of millionths of a gram-molecule per 1,000 cc. air in 1,000 minutes at 15° C. This figure is given in brackets at the end of the reference. They also classified the chemicals into groups of low, medium or high toxicity. Their discussion on the correlation of toxicity and chemical constitution is of far greater importance than the individual values they recorded for each substance, and the list in the Appendix is chiefly useful to show that the toxicity of a substance in air is no criterion of its toxicity in the soil.

Fleming (1925) carried out similar experiments on third-instar larvae of the Japanese beetle (*Popillia japonica*, Newm.). His results were expressed as the number of mg./litre necessary to cause death within 24 hours at 26·7° C. Some substances were also tested in water.

Acknowledgements.

The writer wishes to acknowledge gratefully the assistance of the Imperial Institute of Entomology both in library facilities and in the preparation of a carefully checked species list. Thanks are also due to Mr. C. T. Gimingham for reading through the manuscript and making many helpful suggestions and criticisms and to Mr. A. G. Pollard for kindly providing a summary of recent unpublished work carried out in his department. Professor J. W. Munro and Dr. Hubert Martin have also read the review through critically, and the writer is particularly indebted to Dr. Martin for pointing out and correcting many technical errors.

GENERAL CONSIDERATIONS.

Methods of Application.

The particular methods of application suitable for certain chemicals, insects and conditions are detailed under the substance concerned, but a general survey of the subject, including brief descriptions of the types of apparatus employed, is given here.

(*a*) SOLIDS.

(i) *General Application.*

The application of solid fumigants to the soil is a comparatively simple matter and similar to the application of chemical fertilisers. If the substance is finely ground or granulated, it is most evenly applied by a manure distributor (*e. g.* Leach, 1929); where this is not available or suitable, the substance may be broadcast by hand. The usual methods of cultivation may then be used to incorporate it with the soil, *i. e.* ploughing, harrowing, disking or cultivating. Miles (1929) advocates the rototiller type of cultivator as being suitable for this operation, especially for contact insecticides. A hopper to feed the substance immediately in front of the tines, or for a plough, into the furrow, converts the standard implement into one suitable for distribution and incorporation of fumigants.

(ii) *Application to limited Areas.*

Certain substances, such as p-dichlorbenzene, are more usefully applied in small discrete doses in holes in the ground. This may be advisable when treating grass-land, the surface of which cannot conveniently be disturbed, or when applying poisons to insects already aggregated into small areas by means of baits. Barnard (1884), Jarvis (1924 *a*), Makhnovskiĭ (1928), and Kostenko (1928) have devised relatively simple hand apparatuses to facilitate the introduction of small quantities of solids into the soil. Basically they consist of a tube and a container; the tube is forced into the soil, the nozzle being protected, and the depth regulated by an adjustable bracket; a regulated amount of chemical is then allowed to flow into the hole thus made. For applying calcium cyanide to bait rows, Miles (1929) recommends a small hand drill with a hopper attached. Where labour is cheap, or only small areas are involved, the holes may be made and the chemical inserted by hand.

(*b*) LIQUIDS.

(i) *The Application of small Quantities of pure Liquids.*

Carbon disulphide is the most widely used liquid soil fumigant, and many types of apparatus have been devised for its application. The best known of these is the pal injector, which was developed for the purpose of applying small amounts of carbon disulphide at regular intervals to control the vine *Phylloxera* in France. Only rarely have such instruments been used for other substances.

These injectors consist of a long central tube terminating in a spike (pal). A long narrow piston works in the upper portion of the tube. A container surrounds this and communicates with a dosage chamber immediately below the piston, which is held in the up position by a spring surrounding it. When the piston is depressed, the liquid in the dosage chamber transmits the pressure hydraulically to a valve which opens and allows the liquid to be forced out of the hole at the bottom of the spike. The piston automatically closes the communication between the container and the dosage chamber as it descends, and when the action of the spring causes it to return, the liquid is free to flow into the dosage chamber again. Variations and improvements largely concern the position and type of the valve which may be at the bottom of the spike (*clapet inférieur*) or at the side (*clapet lateral*), and in the connection between the container and the dosage chamber. A good detailed account of the various types, with figures, is given by Vermorel and Crolas (1915). A similar apparatus was described by Slingerland (1894).

For application of carbon disulphide on a larger scale, several types of "plough" were constructed in France. These consisted of a tank and usually a rotary pump working off the wheels of the plough to which it was attached and a device to regulate the flow of liquid into the furrow. Such ploughs are described and figured by Chauzit (1884) and many other contemporary writers, Vermorel and Crolas (1915), Feytaud (1923) (who stated that one man and a horse drawing a plough-injector did the same amount of work as five men working with hand injectors), and Emel'yanova (1935). A more elaborate and modern type is described anonymously (1940). The disadvantage of most of these implements is the difficulty of inserting the fumigant sufficiently deep.

(ii) *The Volatilisation of Liquids.*

Gaumont (1927) for chlorpicrin, and Riley (1928) for carbon disulphide, have described methods of volatilising the toxic substance and leading the vapour in pipes into the soil. Such a method can only be adopted in very limited areas such as glass-houses, and Riley made use of piping already laid on in a glass-house for the purpose of steam-sterilising the soil.

(iii) *The Application of large Quantities of Liquids.*

Partly to reduce toxicity to plants, and partly to secure better dispersion, the recent trends in soil insecticides have been toward the use of emulsions, and the problems involved in the application of large amounts of liquid to the soil are similar to those in the spraying of large orchards. Such measures are limited by the presence of readily available water. Even under favourable circumstances about two gallons of liquid per square yard must be applied to secure adequate penetration and the application of some 10,000 gallons or 40 tons of liquid to the acre is an expensive and considerable task. It has, however, been accomplished in the large-scale treatment of grassland in North America to control the spread of the Japanese and similar beetles.

Early methods depended on a gravity feed (*e.g.* Davis 1920*a*, for sodium cyanide solution), but more recently power sprayers have been developed (Strong, 1931 : Fleming and Baker, 1935). Instead of having a reservoir of diluted emulsion, it is convenient to regulate the addition of a stock emulsion to the main water supply by means of flow meters and valves ; such an arrangement is described by Leach (1925). Merritt *et al.* (1933) adopted this technique in pumping a carbon disulphide emulsion through a canvas hose through the walls of which the carbon disulphide could seep uniformly. They applied the emulsion at the rate of 2½ U.S. gals./sq. ft. to an area of 600 sq. ft. per hour of operation, using one 200-ft. length of porous hose.

(iv) *Special Methods.*

In special circumstances the area to be treated (*e.g.* around a small tree) has been surrounded with a low metal cylinder to contain and limit the emulsion (Fleming and Baker, 1935). It is common practice in America to distribute nursery stock of bush and ornamental trees with the roots surrounded with a ball of soil wrapped in burlap. In order to comply with quarantine regulations it is necessary to ensure that no Japanese beetle or similar beetle larvae are present in this "balled stock", and a special dipping technique has been developed for their control. It is usually carried out at a constant, temperature and when a toxic gas is used, in order to prevent the poison affecting the aerial parts of the plant, these are immersed upside down in water (Fleming and Baker, 1935).

Many workers have attempted to overcome the difficulties of applying toxic liquids either by adsorbing or absorbing them on suitable dusts or by converting them to jellies and applying them as solids.

The Distribution of Insecticides in the Soil.

(i) *Fumigants.*

A considerable amount of work has been carried out on this subject, particularly with reference to carbon disulphide, under which heading details will be found. It is, however, worth while considering some of the factors likely to affect distribution.

Bywaters and Pollard (1937) state that "Whatever may be the physical problem involved (*i. e.* either simple diffusion and/or gravitational flow) the rate of movement of vapour through the soil seems a decisive factor, since this decides not only the actual concentration reached in a given time but also the period over which a lethal dosage is maintained. The rate of movement will be influenced presumably by the amount of interstitial space between the soil particles and/or the gross porosity of the soil, by factors tending to destroy the fumigant (chemical interaction with soil constituents, bacterial decomposition, etc.) or by conditions which may render the fumigant partially or temporarily inoperative (physical absorption, dissolution in the soil water)".

According to Pollard (unpublished), an examination of soils and various sand-silt-clay-organic matter mixtures demonstrated that structure rather than the ultimate composition of the soil was the major factor affecting rates of diffusion.

For the distribution of a fumigant to be effective it must move sufficiently rapidly to saturate the soil in a comparatively short time, but not so rapidly that a lethal concentration cannot persist long enough to kill the insects. The ideal circumstances are those therefore in which the factors influencing diffusion have moderate, and not extreme, values. A further analysis of these factors based on the statement quoted from Bywaters and Pollard may now be considered. The major factors controlling pore space in a soil are as follows :—

(i) Its mechanical composition.
(ii) Its moisture content.
(iii) Its degree of compactness.

Comparatively little experimental work has been done on (i), though Higgins and Pollard (1937) suggested that the tendency of carbon disulphide to penetrate more readily into the lower depths of a Beaconsfield soil than a Slough soil might be accounted for by the relatively coarser texture of the former, which assisted gravitational flow. There is a considerable amount of empirical evidence supporting the part played by factors (ii) and (iii), many authors having found fumigations ineffective in wet and in compacted soils. Again direct evidence is scanty, but both Leach (1920) and Fleming (1923) have found that the diffusion of carbon disulphide is much more rapid in dry than in wet soils. This was also confirmed by Pollard (unpublished), who also reported that at the same water content diffusion rates increased with the colloidal matter present in the soil, organic matter being more effective than clay in this respect.

Among other factors affecting the diffusion process itself, temperature is one of the most important. Although it does affect the rate of diffusion, according to Leach (1920) it will not affect the ultimate range of the fumigant, and its influence on diffusion must be carefully distinguished from its effect on evaporation or volatilisation of the fumigant and on the metabolic processes of the insect.

Keen (1931) states that the following additional factors affect the mechanism of normal gas exchange in the soil :

(i) Soil temperature changes causing expansion and contraction of air.
(ii) The effect of winds in forcing in or sucking out air from the soil.
(iii) The influence of barometric changes in causing compression or expansion of soil air.

Such factors do not appear to have been investigated with special reference to soil fumigation, but they should be borne in mind when planning or interpreting experiments on this difficult subject.

Pollard (unpublished) has also investigated the properties of the fumigant itself which affect diffusion, and finds vapour pressure, solubility in water and decomposition by, or combination with, soil constituents to be the most important.

The most important conclusion to be drawn from all the work on the distribution of fumigants in the soil is that the greatest loss of fumigant occurs from the surface of the soil (O'Kane, 1922*a*; Fleming and Baker, 1935; Higgins and Pollard, 1937). Any methods of decreasing this loss by deeper injections, covering the soil, or flooding the top inch or so of soil, should make for more effective results, although Higgins and Pollard go so far as to state that even with these aids it is impossible to achieve a lethal concentration at the surface. Later experiments (Pollard, unpublished) gave very successful results when treated soil was either covered or "sealed" by flooding. These results all refer to carbon disulphide, but the same appears to be true for p-dichlorbenzene (Chigarev, 1930) and probably for most substances.

(ii) *Solutions and Emulsions.*

The modern use of emulsions as soil insecticides brings this problem to the fore. Apart from the work of Fleming and Baker (1935) on carbon disulphide emulsions

(which is discussed under that heading), very little has been done. Assuming an even application of the liquid, which should not be difficult to accomplish, lateral distribution does not enter into this question. What evidence there is on vertical distribution suggests, as one would expect, a high concentration of the poison in the top few inches of soil resulting from its filtering action, and weaker concentrations in the lower layers. The degree of penetration depends on the type of soil, its moisture content and the total amount of liquid applied. For pyrethrum emulsions, Headlee (1930) showed that the emulsifying agent, as well as the pyrethrum, was taken up in the surface layer of the soil. He also found less absorption in sandy soil.

Experimental Methods of Assessing the Toxicity of Soil Insecticides.

(A) Laboratory Experiments.

In order to avoid some of the obvious difficulties of soil insecticide tests, some investigators have exposed the insect to the chemical in air or water instead of in soil or have used this method as a preliminary sorting technique. It was usually found, however, that the results in the two media were not comparable, and that substances which were toxic in air were quite ineffective in the soil. The unnatural conditions for the test insect also lessened the value of such work, although interesting results were sometimes obtained by these methods, such as the discovery of the usefulness of $\beta\beta'$ dichlorethyl ether as a soil fumigant by Lehman (1933). Such tests have usually been carried out in Erlenmeyer flasks (Fleming, 1925; Lehman, 1933, etc.), and the technique is similar to that used by Strand (1930) for toxicity tests on stored product insects. More elaborate methods have been described by Bovingdon (1934) which could be applied equally well to soil insects.

For experiments in soil much simpler arrangements are normally used, the simplest of all being the ordinary flower pot (whence the term pot experiments commonly applied to such tests) or wooden or metal boxes. These are filled with soil which may have been previously mixed with the substance to be tested, or this may be added later. The test insects may be introduced before the fumigant to allow them to acclimatise themselves to the conditions, or they may be introduced any length of time afterwards in order to ascertain the period over which the substance is effective.

Gough (1942) used a series of shallow cylindrical containers arranged vertically on top of one another, each with a bottom of coarse wire mesh ($\frac{5}{16}$ in.) which was sufficiently open to permit the free movement of the insects and sufficiently close to retain the soil. This enabled the test insects to escape from the zone of the fumigant at least downwards, as they would be able to do in the field. Tattersfield (1928) showed that a given concentration of naphthalene killed wireworms in a closed container, but that in practice, before that concentration was reached, the insects, if free to do so, moved out of the range of the fumigant.

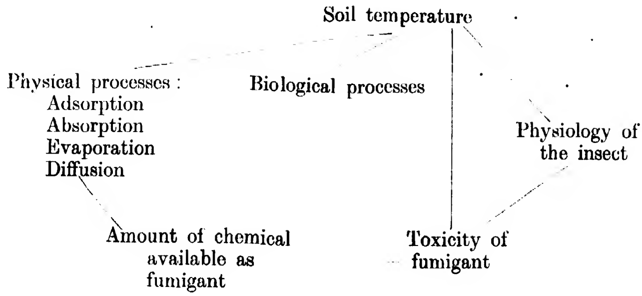
Both Gough (1942) and Fleming (1942) have emphasised the desirability of conducting experiments under controlled conditions and with one type of soil. Fleming found that larvae of the Japanese beetle varied in their susceptibility to stomach poisons according to the time of the year, the source from which they were obtained and the period of time elapsing between digging them in the field and using them in experiments. He therefore advised that all toxicity experiments should be made comparative by using the same standard insecticide in every test in order to eliminate these variations.

It is advisable therefore to control or, failing that, to measure the following factors:—

(a) *Temperature.*

This will affect the diffusion (*q.v.*), evaporation or volatilisation of the fumigant, biological processes (e.g., bacterial decomposition) tending to destroy it, and the

susceptibility of the insects. The following diagram modified from Jones (1933) illustrates the relationship of these processes.



Both Gough and Fleming found it necessary to construct constant temperature chambers. Gough used an underground one so that experiments could be carried out in summer at temperatures similar to those prevailing in the soil. Fleming's chamber was constructed because it was found that tests which would have taken six weeks to perform at temperatures of 55–60° F. could be completed within two weeks at 80–85° F. in the chamber.

(b) *Soil Moisture.*

This also has an important effect on the physical processes of diffusion (*q.v.*) and sorption of the fumigant. It may also, especially at extremes, have a direct effect on the insect, and Fleming (1942) found that the activity of Japanese beetle larvae was affected in excessively dry soils. Gough used a trial and error method to solve the difficult problem of bringing a large volume of soil to a definite water content.

(c) *Soil Type, average Particle Size and Degree of Compactness.*

These factors again affect the physical processes, and it is advisable to standardise them as far as possible. For comparable experiments the soil should be derived from the same source and level (*e. g.* top soil only). The particle size of the same soil at the same moisture content can be kept roughly constant by sieving through a standard riddle. The compactness is most conveniently regulated by introducing a fixed weighed amount of soil into a fixed volume by exerting as far as possible the same amount of pressure. Various devices to measure compactness have been suggested, and one method is discussed by Bywaters and Pollard (1937). By using this method to bring a soil sample to the same degree of compactness as the main bulk of soil for an experiment, they were able to measure the pore space of the sample, by the displacement of the air with a non-wetting liquid such as carbon tetrachloride, and thus calculate the pore space of the main bulk. This enabled them to check the efficiency of their standard methods and also, if necessary, to study the relationship of pore space with any other factor.

(d) *Period of Exposure.*

Soil insecticides are allowed to act as long as they are present in the soil, and Gough (1942) thought that short-period experiments would be too far removed from practice to be of much value. He therefore chose six days as the minimum satisfactory period. As Higgins and Pollard (1937) find that concentrations of carbon disulphide are uniformly low after 24 hours, it is possible that for this and similar substances a shorter period would be effective. On the other hand, for

substances like lead arsenate several weeks would be necessary for adequate testing, but it must be remembered that the longer the period, the more difficult it is to find dead insects as these decay very rapidly in the soil.

(e) *Test Insects.*

The precautions usual in toxicity tests of standardising pre- and post-fumigation treatment, condition, stage and species of the insect should be observed.

(f) *Design of Experiments.*

The possibilities of variation are so great that the necessity for adequate replication and suitable design of the experiments, so that the results can be statistically analysed, cannot be too highly emphasised. A suggested figure is 20 insects per test and five replicates at each concentration, though obviously these numbers will vary with the circumstances.

(B) Field Experiments.

Field experiments on soil insecticides involve a considerable amount of time, labour and expense. For an experiment to be of value the arrangement must be such that it is capable of statistical analysis, and the results should preferably be recorded primarily in terms of numbers of insects rather than of crop yield. Although the latter is important, complications may arise through a direct effect of the chemical on the crop.

The determination of the numbers of insects before and after treatment, or the numbers of dead and living insects after treatment, usually requires more or less accurate soil sampling. This subject has been discussed by Jones (1937) and Ladell (1936, 1938) with special reference to wireworms, from both the statistical and technical aspects.

It is usually not possible to deal with more than about six different treatments if adequate sampling is to be done, and the final result often cannot be determined until the crop has reached maturity. This greatly limits the number of field experiments that can be performed in one season, and the results then obtained may only be applicable to that season and to the particular soil type concerned.

Small plot experiments (of the order of 1-10 square yards) have been suggested and occasionally used as a convenient compromise between preliminary pot experiments and final field experiments, but they also have disadvantages. The principal one is the difficulty of confining the insects to the treated area. This is sometimes overcome by sinking metal or wooden walls into the ground, but this disturbs the texture of the soil. Also on such small plots the amount of soil removed or disturbed for examination is liable to be a significant proportion of the whole. In addition, if it is necessary to infest the plots artificially, the number of insects required is very large and the amount of time spent in collecting or rearing them might well be disproportionately great.

(C) The Provision of Soil Insects for Experiments.

Insecticide experiments necessitate the use of very large numbers of insects. These may either be reared in the laboratory or collected in the field. The breeding of hundreds or thousands of insects per week is no easy matter with stored product pests which lend themselves to large-scale manipulation, and for the breeding of which a more or less standardised technique has been evolved, but it is incomparably more difficult with soil insects. Many of these, such as certain wireworms and Scarabaeid larvae, have long life-histories of three to five years, and difficulty is experienced in bringing even a few to maturity. Many are very susceptible to handling. In most experiments, and also in breeding or storage cages, insects have to be concentrated to a much greater extent than under natural conditions, and this increases the risk of diseases. The writer lost several thousand wireworms through a fungus

attack in a few months in this way, and the results of a great number of experiments were invalidated. If the insects are collected in the field, there may be differences of resistance depending on the season or the source from which they were obtained. Such differences can be overcome to some extent by comparing the results in each series of tests with that of a standard insecticide used under the same conditions.

The Effect of Soil Insecticides on Plants and Micro-organisms.

As has already been stated, no effective soil insecticide can be applied indiscriminately to growing plants. As a rule, the margin between insecticidal and phytocidal doses (if one exists) is so small that great care must be taken. Many factors, apart from the specific properties of the chemical and plant, are involved. The concentration of the chemical at the plant roots, which in the case of point injections depends on the distance they extend from the plant, the temperature and condition of the soil, and the age and condition of the plant, must all be considered. The extent of the damage may vary from a temporary wilting or retardation of growth to the death of the plant. The physical state of the chemical is also important. For example, Fleming and Baker (1935) point out that whereas it was impossible to inject carbon disulphide in insecticidal concentrations when the soil was in suitable condition without causing serious injury to plants, these could be successfully treated with a carbon disulphide emulsion. They also found that, when in a dormant condition, the roots of many species of ornamental grasses, herbaceous and perennial plants, deciduous shrubs and trees could be immersed in a weak carbon disulphide emulsion without injury, whereas roots of evergreens were generally injured at all seasons. There appear to be few generalisations of this type that can be made, and the original paper must be referred to for indications of the degree of toxicity to plants for any given substance. Where marked effects were observed, the present writer has usually noted them in the appropriate place, but references to experiments on the direct effect of chemicals on plants have not been specially sought out. A number of such references are given by Bourcart (1926).

Very early in the use of carbon disulphide, Girard drew attention to the unusually fine crops of corn and potatoes grown on land previously treated with carbon disulphide (Vermorel and Crolas, 1915). The vigorous growth and deep green colour of vines on treated land were also remarked upon, but contemporary investigators were unable to come to any satisfactory conclusion as to its cause. Later it was shown to be generally associated with an immediate drop, and later, a rapid increase in the numbers of soil bacteria, the increase continuing to a point much higher than the original numbers. The phenomenon was referred to as partial sterilisation, implying that although all the soil pests and some of the beneficial bacteria were destroyed, enough of the latter remained alive to restore the fertility of the soil. Martin (1936) has given an excellent summary of the theories advanced to explain the increased fertility of soil treated by various chemicals, and his account (under "Soil Treatment"), and the references he cites, should be consulted for further details.

The references to the effect of different chemicals on the numbers of soil micro-organisms and their activities in the soil are too numerous to consider in the present review, though some are noticed under the chemical concerned. In view of the importance of carbon disulphide, the work of Fleming and Baker (1935) may be mentioned. They found that the application of small amounts of this substance to the soil resulted in an increase in the numbers of fungi, little change in the numbers of bacteria, no effect on nitrates, but an accumulation of ammonia in the soil. The application of carbon disulphide emulsion caused an increase in the numbers of bacteria, which ultimately dropped to the original level, and an increase of ammonia, but, as before, had no effect on soil nitrates. Water alone did not cause these responses, but it did complicate the effect on the fungi.

An interesting phenomenon was recorded by Tattersfield (1928) for naphthalene. He found that naphthalene disappeared far more rapidly from soil previously treated

with it than in previously untreated soil. Bacterial counts confirmed his suggestion that a certain species of bacteria was able to utilise this substance as a source of energy, and increased in numbers so much with one treatment that they could more rapidly reduce the naphthalene of a second treatment. As might be expected, the disappearance was more marked in organic soils, which were richer in bacteria.

Enough has been said to indicate that this factor is one which should not be overlooked when working on soil insecticides. The necessary technique is, however, slow and laborious, and time would probably only permit of careful studies on a few substances shown to be promising.

THE MORE IMPORTANT SOIL INSECTICIDES.

(Arranged in alphabetical order.)

Calcium Cyanide ($Ca(CN)_2$).

Crystalline. In the presence of water, calcium cyanide gives off hydrocyanic acid gas according to the following equation :

$$Ca(CN)_2+2H_2O = Ca(OH)_2+2HCN.$$

It is the most widely used of the cyanides for the control of soil insects and can be obtained either finely ground or in a granular form. By another process of manufacture a product more akin to the acid cyanide $CaH_2(CN)_4$ is obtained. This product is capable of generating more hydrocyanic acid.

Calcium cyanide may be applied in solution, or as a solid, in one of the following ways :

(1) In holes at regular intervals or at the base of plants to prevent or control insect attack.

(2) Drilled in rows with a seed drill, using a granular form. This method may also be used in conjunction with a bait to attract the insect into limited areas.

(3) Broadcast on the surface by hand or by fertiliser distributor and worked in by harrowing or ploughing.

Experiments in Air.

Melander (1924) described experiments to determine the amount of volatile poisons required to saturate a given quantity of soil and the subsequent rate of killing the bean weevil (*Bruchus* sp. ?). Calcium cyanide was very effective, killing the beetle within 28 minutes, whereas sodium cyanide took over half a day. He calculated that almost 700 lb./ac. (780 gm./sq. m.) to a depth of one foot would be necessary to saturate the soil with a toxic vapour.

Fleming (1925) ; minimum lethal dose 16 mg./l.

Experiments in Soil.

ORTHOPTERA.

Gryllidae.

Watson (1925) found 1,200 lb./ac. (134 gm./sq. m.) evenly distributed on the surface of the ground gave an effective but expensive control of mole crickets. Frappa (1931) recommended that it should be distributed in the underground galleries of *Brachytrypes membranaceus* var. *colossea*, Sauss., to control this pest, which was destroying the roots of coffee and other plants.

DERMAPTERA.

Forficulidae.

Steinweden (1934) found ¾ oz. (21 gm.) gave an effective control of the earwig, *Forficula auricularia*, L., in balled nursery stock within 24 hours at 60° F. (15·6° C.).

The cyanide was placed on the inner side of the burlap covering the soil ball and the ball rewrapped. Mackie (1934) in California obtained a similar result using 1 oz. (28 gm.)/cu. ft. (1 kg./cu. m.) of soil. All the earwigs were dead after one hour.

ISOPTERA.

Jepson (1926) found $\frac{1}{10}$–$\frac{1}{2}$ oz. (2·8–14 gm.) drilled below tea bushes did not prevent termites, *Calotermes* sp., attacking the bushes.

THYSANOPTERA.

Miles (1927) recommended granular calcium cyanide at the rate of 1 lb./12 cu. ft. (1333 gm./cu. m.) of soil to kill hibernating thrips which might otherwise attack orchid seedlings.

HEMIPTERA.

Aphidae.

Cutright (1925) was able to kill numerous root Aphids (*Prociphilus erigeronensis*, Thos.) on white asters by digging in 1 gm. of cyanide around each plant. Higher amounts seriously injured the asters. In an attempt to control the black peach aphis (*Anuraphis persicae-niger*, Smith) he found that $\frac{3}{8}$–$\frac{3}{4}$ oz. (10–20 gm.) per tree resulted in the death of several peach trees. French and Levick (1925) also found that 1 oz. (28 gm.) affected the root system of pear trees when it was scattered on the surface of the soil and dug in to a depth of 6 in. (15 cm.), and it was not very effective in controlling the pear woolly aphis (*Eriosoma pyricola*, Bak. & Dav.).

LEPIDOPTERA.

Aegeriidae.

Headlee and Ilg (1926) were unable to kill larvae of the raspberry crown borer (*Pennisetia marginata*, Harr.) with calcium cyanide without injuring the plants.

Noctuidae.

Ries (1929) obtained an effective control of pupae of the Iris borer (*Macronoctua onusta*, Grote) by watering the soil around the plants with a solution of $\frac{1}{8}$–$\frac{1}{4}$ oz. of calcium cyanide in 1 U.S. gal. (0·9–1·8 gm./l.). This did not injure the plants.

Crambidae.

D'Emmerez de Charmoy (1929) recommended a 1/500 solution of calcium cyanide for the control of *Crambus seychellelus*, Fletcher, in lawns. Noble (1932) found 2 oz./sq. yd. of a 40–50% calcium cyanide dust (30 gm./sq. m.) ineffective against sod webworms in lawns. Moutia (1934) destroyed large numbers of *Crambus emmerezellus*, de Joannis, a pest of lawns, with a solution of calcium cyanide of 2 gm./l. followed by thorough watering or flooding.

COLEOPTERA.

Scarabaeidae.

Box (1925) obtained up to 85% kills of white grubs (*Lachnosterna* sp.) on sugar-cane by scattering 1 oz. (28 gm.) over the soil for a radius of 9 ins. (22·5 cm.) around the stool, followed by a thorough watering. Zappe and Garman (1925) broadcast a coarse dust containing 40–50% calcium cyanide at 4 and 6 oz./sq. yd. (136–206 gm./sq. m.) with a hand fertiliser drill on a lawn infested with Oriental beetle grubs (*Anomala orientalis*, Waterh.). After treatment the lawn was thoroughly wetted and a satisfactory kill was obtained. $\frac{1}{3}$–1 oz. (9–28 gm.) doses applied in holes 12–24 ins. (36–72 cm.) apart were ineffective. Britton and Zappe (1926)

recorded complete mortality of the same insect in lawns at 4, 6 and 8 oz./sq. yd. (136, 204, 272 gm./sq. m.), but the grass was damaged by the treatment. A fine-grade proprietary calcium cyanide (Cyanogas) at 1, 2, 3 and 4 oz./sq. yd. (34, 68, 102, 136 gm./sq. m.) also gave complete kills without injuring the lawn. Jarvis (1927 *a*) found that 10 grains (0·65 gm.) placed 2 ins. (5 cm.) above eggs of the cane-beetle (*Dermolepida albohirtum*, Waterh.) resulted in a complete kill within 24 hours. Uichanco (1928) recommended that sugar-cane infested with grubs of *Leucopholis irrorata*, Chevr., should be treated with granular calcium cyanide at 10 gm./hill, 10 cm. deep. Whilst this measure would not save the infested plant, it would reduce centres of infestation for future crops. McCarthy (1928) obtained a 70% kill of the wheat root grub (*Anodontonyx tetricus*, Blkb.) in an experimental plot treated with 30 oz./100 sq. ft. (90 gm./sq. m.). Applied in the field through a manure hopper at 20 lb./ac. (2·2 gm./sq. m.) it was quite ineffective. Nichol (1935) reported fairly good results in the control of larvae of the fig beetle (*Cotinis texana*, Casey) by applying a teaspoonful of calcium cyanide to each larval tunnel. The method was only satisfactory in a dry soil. Chigarev (1932) obtained a 93·5 % kill of Scarabaeid larvae with 60 gm. doses of calcium cyanide in holes 20 ins. (50 cm.) apart (240 gm./sq. m), but found it uneconomic. Jarvis and Burns (1926) recorded a reduction of 37 % of cane grubs (*Dermolepida albohirtum*, Waterh.) attacking sugar-cane with ½-dram doses. Burns (1926) obtained a 40% kill of the same species by the application of four doses, each of ⅛ oz. (3 gm.) per stool.

Elateridae.

Horsfall (1924) obtained an 84% average kill of wireworms attacking early cabbages near Philadelphia by applying 6–8 gm. of granular calcium cyanide 3 ins. (7·5 cm.) from each plant in the furrows left by cultivation. The plants with-s ood doses up to 10 gm. without injury. Campbell (1924), after recording promising results in preliminary pot experiments, applied calcium cyanide on a field scale at 200 lb./ac. (22 gm./sq. m.) and was able to secure 75% or higher kills of the wireworms, *Pheletes californicus*, Mannh., and *P. occidentalis*, Cand. It was applied 4–6 ins. (10–15 cm.) deep or at the level at which the wireworms were most abundant. The best results were obtained in the spring and when the soil was neither too compact nor too loose. Planting could be carried out 7–10 days later. Headlee (1925) found flake calcium cyanide at the rate of 0·1 oz./sq. ft. (30 gm./sq. m.) applied in furrows 1 in. (2·5 cm.) deep and 6 ins. (15 cm.) apart killed wireworms (probably *Melanotus* sp.) within 3 ins. (7·5 cm.) laterally and 12 ins. (30 cm.) vertically. Drilled 4 ins. (10 cm.) from cabbage seed, 0·2 oz./linear foot (18 gm./m.) were required to kill the wireworms, but at this rate three-quarters of the plants were killed. In 1926, using similar rates, 0·11 and 0·126 oz./sq. ft. (33 and 38 gm./sq. m.), he also reported some control. Horsfall and Thomas (1926) compared various methods of application of the granular cyanide in the control of wireworms (*Pheletes* and *Agriotes* sp.) on vegetable crops. Up to 250 lb./ac. (28 gm./sq. m.) broadcast with a lime spreader, only resulted in 5·7% carrots being damaged by wireworms, compared with 12% in the control. When applied in plough furrows 14 ins. wide and 5 ins. deep (35×12·5 cm.) at 300 lb./ac. (33 gm./sq. m.), 17·2% potatoes were damaged compared with 37·3% in the control. The following year beet was grown in the same field and no plants were lost on it compared with a 50% loss on an untreated field. Using a special applicator attached to the plough, at 225 lb./ac. (25 gm./sq. m.), 17% of the carrots were damaged, but only 0·1% in the following season. All these applications were made in the spring; summer applications to growing crops resulted in the death of the plant if the rate was high enough to kill wireworms. Britton and Anderson (1926) recommended calcium cyanide drilled into soil at 100 lb./ac. (11 gm./sq. m.) to control *Pheletes ectypus*, Say, injuring tobacco in Connecticut. After treatment, the plants could be set out within a week. Calcium cyanide could not, however, be applied when the plants were on the ground (Britton 1926). Headlee (1927) made further field tests using a special plough attachment, and at 0·1 oz./sq. ft. (30 gm./sq. m.) secured an 86% kill of wireworms 14 days after

application. Lacroix (1934) applied it in furrows at 100 lb./ac. (11 gm./sq. m.) 4 ins. (10 cm.) deep and covered with soil, and found all wireworms (*Pheletes ectypus*, Say) within 6 ins. (15 cm.) on each side were dead. Applied at the same rate with a corn planter to each row of young tobacco plants 2½–3½ ins. (8–9 cm.) deep, a 66% kill was obtained in cold weather after four days. McDougall (1934) found it ineffective in controlling *Lacon variabilis*, Cand., when the cyanide was drilled in rows in sugar-cane fields 2 ft. (60 cm.) apart at 200 lb./ac. (22 gm./sq. m.). When applied sufficiently near the plants to kill the wireworms, the plants were also killed. Strong (1937) reported a 78% kill of *Pheletes californicus*, Mannh., and *P. canus*, Lec., attacking onions in Washington after the application of cyanide at 400 lb./ac. (45 gm./sq. m.). Morrill and Lacroix (1938) found that calcium cyanide drilled into the soil at ¼–½ oz. (7–14 gm.) per plant beside newly set out tobacco plants killed both wireworms (mainly *Pheletes ectypus*, Say) and plants. Kharitonov (1939), after a crop of lupins had been destroyed by wireworms, treated the soil with a preparation of calcium cyanide applied in holes 8 ins. (20 cm.) deep and 20 ins. (50 cm.) apart at 15, 20 and 25 gm. per hole (60 to 100 gm./sq. m.), and measured its effect by the numbers of wireworms attracted to baits set out 14 days later. The total numbers attracted to 10 baits in the treated plots ranged from 1–6 compared with 31–82 in the control plots. Wilson (1940) treated seed-beds at 300 lb./ac. (34 gm./sq. m.) broadcast, and only secured a 2% kill of wireworms (probably *Melanotus communis*, Gylh.).

Calcium Cyanide used in Conjunction with Baits for the Control of Wireworms.

The practice of attracting wireworms with baits and then removing or destroying the wireworms is a long-established one in glasshouses. The extension of this to a field scale appears to have been first suggested by French (1916) (see under "Sodium cyanide") and later (1924 onwards) developed in America with the increasing use of calcium cyanide, which proved particularly suitable for the purpose, as it could be obtained in a granular state which could be drilled with a seed drill.

Campbell (1924) proposed the aggregation of wireworms with baits and subsequent fumigation with calcium cyanide. Spuler (1925) also suggested the use of baits, and proposed germinating seeds of garden vegetables and flowers for this purpose. The rate of application of cyanide could then be reduced to 100 lb./ac. (11 gm./sq. cm.), which should be applied 14 days after the setting out of the baits. When flour and potato baits had been placed in holes, a teaspoonful of cyanide per hole was 85–95% effective. Campbell (1926) recommended that after the concentration of wireworms to the baits, which were drilled in rows 2½ ft. (75 cm.) apart, the rows should be treated with 5–5½ lb./1000 ft. (75 gm./m.). This necessitated rather less than 100 lb./ac. (11 gm./sq. m.) and gave an average mortality of 91%. Horsfall and Thomas (1926) attracted wireworms (*Pheletes* and *Agriotes* sp.) to sweet corn sown in rows 4 ft. (120 cm.) apart. Eighteen days later granular calcium cyanide was worked in at 400 and 200 lb./ac. (45 and 23 gm./sq. m.), resulting in kills of 70–80%. Even better results were obtained with a longer interval of time and the rows 2 ft. apart. Ploughing beforehand to facilitate movement of the wireworms in the soil also resulted in increased kills. C. A. Thomas (1926) also recommended maize sown in rows 2 ft. (60 cm.) apart in the early spring as a trap crop when the wireworms were beginning to move upwards, and about two weeks later calcium cyanide drilled close to the rows at 150 lb./ac. (17 gm./sq. m.) at least as deep as the seed was sown.

Miles and Petherbridge (1927) confirmed the value of this method in experiments carried out in Lincolnshire on *Agriotes* sp. They found bran and germinating wheat the most effective attractants, but stated that baiting was not effective on newly ploughed-out grassland before the sod had decayed. They recorded kills of over 90% with wheat drilled 5 ft. (150 cm.) apart, and 14 days later treated with cyanide at 70–90 lb./ac. (8–10 gm./sq. m.). They also showed that the method could be used successfully in glasshouses, where they recommended the application of 3 lb./100 yards of row.

Hawkins (1936) found a varying response to baits under different conditions. ¼ oz. (7 gm.) cyanide applied to baits gave a 77% kill of wireworms in one season and 53% in another. In 1931 wheat planted in May attracted an average of 12½ larvae per yard of row, but drilling cyanide close to the row caused no reduction in the numbers. The weather was cold and moist. It appeared that the method of baiting was only useful at certain times in the spring and autumn when wireworms were active and soil conditions suitable and there was neither turf nor crop to compete with the bait in attracting wireworms. According to him the gas does not diffuse downwards below the point of injection, and only to a radius of 10 ins. (25 cm.) laterally.

Thomas (1930) summarised the information on the use and best practice of this method in the following recommendations. He states that it must be understood that baiting is meant for use only on small-scale operations, as in market gardens, and he doubts if it would be practicable on an agricultural scale.

1. Remove crop remnants and weeds, and plough and harrow before baiting.
2. Use baits in the spring, when the wireworms are becoming active.
3. The best baits are wheat, oats or corn (maize), drilled in rows about 2½ ft. (75 cm.) apart and 2 ins. (5 cm.) deep.
4. Allow about two weeks to elapse between baiting and treating the rows with cyanide, time enough for most of the wireworms to reach the baits. Too dry or too cold soil may retard their movements.
5. Apply the cyanide when the soil is easily worked, but not wet, as the cyanide does not readily permeate wet soil.
6. Apply the cyanide uniformly with a seed drill, preferably slightly below the level of the bait.
7. Use about 6 lb. of the granular calcium cyanide per 1000 ft. of row; this will amount to almost 100 lb. per acre (11 gm./sq. m.) when the rows are 2½ ft. (75 cm.) apart.
8. Do not plant the regular crop for at least a week or 10 days after this treatment or cyanide gas may injure the plants.

Buprestidae.

Rekk (1932) found calcium cyanide applied in furrows 8–10 cm. deep and 10–13 cm. distant from the trees was ineffective in controlling larvae of the black flat-headed borer (*Capnodis tenebrionis*, L.) attacking fruit trees.

Chrysomelidae.

Driggers (1927) recorded a 95% kill of *Rhabdopterus picipes*, Ol. (cranberry root worm) on cultivated blueberries with an application of ½ oz. (14 gm.) calcium cyanide at the base of the plants and the soil lightly raked towards the plant, which was unharmed by the treatment. Feytaud (1932) killed Colorado beetles (*Leptinotarsa decemlineata*, Say) up to 15 cm. deep in the soil with cyanide at 90 gm./sq. m. applied 10–20 cm. deep; 30–40 gm./sq. m. yielded a negative result.

Cerambycidae.

In an anonymous publication (New Mexico, 1933) it was stated that larvae of *Prionus californicus*, Motsch., buried one foot or more below the surface were unaffected by calcium cyanide at the rates normally used for 5–6-year-old trees. Later (New Mexico, 1935) negative results were obtained when 10 larvae of this insect were caged at the bottom of a trench 6 ft. long and 2 ft. deep treated with cyanide at 4 oz./cu. ft. (4000 gm./cu. m.). Chamberlin (1925) obtained 33% kill of the gooseberry root borer (*Xylocrius agassizii*, Lec.) with applications of 1–3 oz. (28–72 gm.) cyanide per gooseberry bush, and the treatment destroyed the plants.

Cryptophagidae.

Edwards and Thompson (1934) in an attempt to control the pigmy mangold beetle (*Atomaria linearis*, Steph.), broadcast calcium cyanide on the soil and ploughed it in at 5¾ cwt./ac. (72 gm./sq. m.). This treatment had no significant effect either on the yield or the observed numbers of insects.

Curculionidae.

F. F. Smith (1932) found calcium cyanide ineffective in controlling third- and fourth-instar larvae of the vine weevil (*Otiorrhynchus sulcatus*, F.) at rates that were not injurious to cyclamens and primulas on which the grubs were feeding. W. H. Edwards (1934) recommended 1½–2½ oz. (42–70 gm.) per tree to control the larvae of the weevils, *Prepodes vittatus*, L., and *Pachnaeus litus*, Germ., attacking the roots of young citrus trees in Jamaica. Krasnyanskii (1937) obtained a 72–78% kill of *Otiorrhynchus turca*, Boh., grubs with 1 oz./sq. yd. (34 gm./sq. m.).

HYMENOPTERA.

Sphecidae.

F. F. Smith (1925) controlled the Cicada killer (*Sphecius speciosus*, Dru.) by placing a teaspoonful of cyanide in the opening of each burrow of the insect.

Andrenidae.

Sanders (1928) failed to control the solitary bee (*Andrena perplexa*, Smith) burrowing in lawns by dusting with calcium cyanide. The grass was injured by the treatment.

DIPTERA.

Cecidomyiidae.

Miller (1925) found that 1½ lb./200 sq. ft. (36 gm./sq. m.) worked into the soil with a spade gave complete control of larvae and pupae of the pear leaf-curling midge (*Dasyneura pyri*, Bch.). Staniland and Walton (1930) stated that ½, 1 and 2 oz./sq. yd. (17, 34, 68 gm./sq. m.) worked into the soil in June to a depth of about 4 ins. (10 cm.) effected complete control of the pear midge (*Contarinia pyrivora*, Ril.) in a light garden infestation. A considerable reduction also resulted when these amounts were applied to a heavy wet soil in October.

Anthomyiidae.

Hille Ris Lambers (1932) found that all pupae of the beet fly (*Pegomyia hyoscyami*, Panz.) were killed in soil containing 0·1% cyanide.

Trypetidae.

Wiesmann (1933) found it useless for the control of immature stages of the cherry fly (*Rhagoletis cerasi*, L.) up to 20 gm./sq. m.

MYRIOPODA.

C. A. Thomas (1926) recommended granular calcium cyanide at 400 lb./ac. (45 gm./sq. m.) for the control in autumn of millepedes in cold frames.

Scutigerella immaculata, Newp. (Glasshouse Symphylid).

In an anonymous publication (Oregon, 1928) failure to control this pest with calcium cyanide at 8 oz./1,000 sq. ft. (2½ gm./sq. m.) broadcast on the surface and dug in is reported. Wymore (1931) obtained 80% kill applying cyanide in furrows 3–4 ins. (7·5–10 cm.) deep in asparagus beds at the rate of ½ oz./linear yard (15 gm./m.). Applied in the field 6-7 ins. (15–17·5 cm.) deep at 125 lb./ac. (14 gm./sq. m.) only a

few individuals near the furrows were killed. Filinger (1931 *b*) found it a very effective remedy applied to the subsoil at 1 lb./75 sq. ft. (61 gm./sq. m.). Michelbacher (1932), applying it broadcast to small plots at 300, 600 and 900 lb./ac. (34, 67 101 gm./sq. m.), obtained 54, 65 and 80% kills respectively.

MISCELLANEOUS.

According to Muir and Swezey (1926), calcium cyanamide containing 40% calcium cyanide, applied at 3 tons/ac. (300 gm./cyanide sq. m.), gave excellent results in fallow land, and killed 96% of various soil pests in ratoon cane. Sugar-cane planted one week after application was uninjured.

SUMMARY.

Up to about 30 gm./sq. m., calcium cyanide has only been effective in about half the references quoted. At rates of 30–60 gm./sq. m. and up to nearly 300 gm./sq.m. it has usually been effective, giving kills of 80% or higher. Used in conjunction with a bait to concentrate insects beforehand, rates of 10–20 gm./sq. m. have given high kills of wireworms under certain favourable conditions.

Carbon Disulphide (CS_2).

Liquid. S.G. 1·256 at 22° C. A colourless oily liquid when pure; commercial samples are yellow and evil smelling.

Carbon disulphide has been more widely used as a soil fumigant both in laboratory and field experiments than any other substance. Its early history is associated with the control of the vine *Phylloxera* (*q.v.*) which swept across the French vineyards at the end of the nineteenth century.

Many different types of apparatus have been devised to facilitate its application and many methods developed for studying its distribution and determination in the soil. Nowadays it is frequently used in the form of an emulsion, and in America especially this has proved highly successful. Fleming and Baker (1935) have brought together and summarised in a very useful paper a vast amount of literature describing its use with especial reference to the Japanese beetle, its determination and distribution in the soil and its effect on micro-organisms and plants. Much of the general information in the succeeding pages has been derived from this summary.

Detection and Estimation.

The most satisfactory methods are those in which the compound is absorbed in alcoholic potash and the amount of carbon disulphide determined colorimetrically, gravimetrically or volumetrically. Fleming and Baker (1935) found volumetric estimation by iodine the best of these methods, and it was also used by Higgins and Pollard (1937). To determine the amount in the soil it is necessary to vaporise the carbon disulphide by passing a warm stream of carbon dioxide-free air through the soil and absorbing the vapour in alcoholic potash. (Equation (1).) This solution is diluted with distilled water, neutralised with acetic acid using phenolphthalein as indicator, taking care to avoid excess acidity. Solid sodium bicarbonate is added and the standard iodine solution is added steadily from a burette until a faint blue colour appears with a few drops of starch solution. The iodine converts the acidified xanthate into a complex sulphur compound. (Equation (2).)

$$C_2H_5OH+KOH+CS_2=C_2H_5OCS_2K \text{ (potassium ethyl xanthate)}+H_2O \quad \ldots\ldots (1)$$

$$2C_2H_5OCS_2H+I_2=(C_2H_5OCS)_2S_2H+2HI \quad \ldots\ldots (2)$$

Tischler (1932) has described a micro-analytical qualitative test in which a yellow colour (pronounced if the carbon disulphide exceeds 1/100,000, and tinged if it exceeds 1/1,000,000) appears when a mixture of diethylamine solution and copper acetate is added to 1 cc. of the solution to be tested.

Distribution of the Gas in the Soil.

This subject has been studied by Fleming and Baker (1935) and Higgins and Pollard (1937). The American workers relied on gas samples taken by aspiration from the soil spaces, though, as they realised, this method is open to the objection of disturbing the equilibrium. They confirmed their results by biological tests. Higgins and Pollard took samples of the treated soil and estimated the amount of carbon disulphide present by the method previously referred to. Both workers stressed the difficulty of achieving a high concentration of fumigant near the surface because of the loss of vapour to the atmosphere and the tendency of the chemical to diffuse downwards. Higgins and Pollard summarised their results derived from experiments carried out in large boxes as follows :

At any given time there is a relatively high concentration in the zone of injection and immediately below it.

There is a rapid decrease of concentration as the surface is approached and a somewhat slower decrease with depth below the zone of injection.

The time-concentration curve for each individual layer represents a sharp rise to a maximum concentration, followed by a slower decline to a low level, which is normally reached in about 24 hours.

Variation in the depth of injection raises or lowers the zone of high concentration without appreciably affecting the surface layer to a depth of 3 ins. (7·5 cm.).

Increasing the amount of fumigant per injection appeared to increase the persistence of an effective concentration without causing a marked change in distribution or the maximum concentration attained.

There were indications that the loss of fumigant from treated soil occurs largely through the surface.

An effective concentration could not be produced in the surface layer by variation of the depth or amount of injection or by covering the surface with sacking.

The nature of the concentration gradient in the soil suggests that movement of the vapour is largely a simple diffusion process, but that in coarse textured or loosely packed soils a gravitational flow (as of a viscous fluid) may occur to a limited extent.

The concentration is uniformly low at all depths after 24 hours, and there is no concentration of practical value after 40 hours.

Fleming and Baker described the area of high concentration around a point of injection as cone-shaped, with the apex close to the point of injection. The maximum lateral diffusion was about 24 ins. (60 cm.), and no increase of dose increased that distance. Thus a large number of small doses would be more effective than the same amount of fumigant injected in large doses further apart.

Börner and Thiem (1921) suggested methods of regulating the action of carbon disulphide by the addition of fish oils and other heavy oils so that its toxicity to plants was reduced and its persistence in the soil increased. They (1925) and other workers have experimented with carbon disulphide in the form of a jelly to facilitate handling and to decrease its volatility.

Decomposition in the Soil.

According to Pollard (unpublished), there is evidence of the decomposition of carbon disulphide in soil. Within limits this decomposition tended to occur with increasing rapidity if the fumigation was repeated. Destruction of carbon disulphide was more marked in soils containing high proportions of organic matter, and resulted in the production of hydrogen sulphide which combined with iron compounds in the soil to cause temporary blackening due to the formation of iron sulphide. These changes were demonstrable only when the oxygen supply was very limited and were largely reversed when the soil was aerated.

Experiments in Air.

Tattersfield and Roberts (1920): low toxicity (526).

Fleming (1925): minimum lethal dose in air 44 mg./l.; in water 215 mg./l. Lehman (1933) found 31·5 mg./l. for a five-hour exposure to be the median lethal dose (50% kill) for the wireworm, Pheletes californicus, Mannh. *Thalenhorst (1937) for third-instar larvae of the cockchafer (Melolontha hippocastani, F.) gave 262 mg./l. for a 24-hour exposure as the minimum lethal dose.*

Experiments in Soil.

(a) *Applied undiluted.*

COLLEMBOLA.

Headlee (1916) used carbon disulphide at ½ oz./cu. ft. (55 gm./cu. m.) to control the mushroom springtail (*Hypogastrura armata*, Nic.). The liquid was poured into holes made in the beds 2½ ins. (6 cm.) deep and 12 ins. (30 cm.) apart. All the springtails were killed, but the treatment was liable to damage the mushrooms.

ORTHOPTERA.

Gryllidae.

Peyran (1913) was able to control mole-crickets (*Gryllotalpa* sp.) with 10 gm. doses poured into holes 50 or 75 cm. apart (40 and 25 gm./sq. m.). Similar recommendations were made by Vermorel (1905), Marchal and Prillieux (1916), Feytaud (1917 and 1933 *a*), Marchal and Foex (1918), and Conte (1928). Feytaud also suggested rates up to 100 gm./sq. m. under certain circumstances, especially where there were no plants. Somewhat higher rates (80 to 130 gm./sq. m.) gave kills of 75 and 90% in Algeria according to Delassus (1923). Sonan (1931) recommended pouring 2 gm. into holes of the cricket, *Brachytrypes portentosus*, Licht., which emerged from the holes at night to cut off plants. In an anonymous publication (New South Wales, 1940) injections of ¼ fl. oz./sq. ft. (76 gm./sq. m.) were advised to control the mole-crickets, *Gryllotalpa africana*, P. de B., and *G. australis*, Erichs., which were causing serious injury to lawns.

ISOPTERA.

Jepson (1926) obtained 95% kill of tea termites (*Calotermes* sp.) building nests under tea bushes and hollowing out the stems with 2 oz. (71 gm.) per bush. Hargreaves (1929) recorded good results in the control of termites attacking citrus stock in Sierra Leone by injecting 10 cc. (13 gm.) per plant 8 ins. (20 cm.) from the plant and 3 ins. (7·5 cm.) deep. Jarvis (1927 *b*) advised the application of 1 to 8 oz. (35–284 gm.) to disinfest soil from which sugar-cane stools attacked by termites had been removed.

HEMIPTERA.

Coccidae.

Gardner (1926) recommended 60 drops (1 fl. dram) of carbon disulphide/4 cu. ft. (6 gm./cu. m.) repeated every week or so for the control of mealybugs (*Pseudococcus* sp.). Schurmann (1922) advised three injections, each of 10 cc., of carbon disulphide/sq. m. (38 gm./sq. m.), 25 to 30 cm. deep, to destroy centres of infection of the scale insect, *Margarodes vitium*, Giard, a pest of grape-vines in South America.

Aphidae.

Phylloxera vastatrix, Planch. (Vine Phylloxera).

The use of carbon disulphide to control this pest is probably the earliest use of a soil insecticide on a large scale. According to Vogt (1924), it was first used in this way by Baron Thénard in 1872, though Willaume (1931) and Fleming and Baker (1935) quote the date as 1869. It was employed in two ways. Firstly, as a means of wiping out a small infestation in a district where the *Phylloxera* had not previously

appeared. Secondly, as a method of destroying or reducing an infestation without harming the vine. Examples of the first method, which may vary according to the regulations of the country concerned, are given by Grassi (1916) and Bourcart (1926). The vine is destroyed and the stocks rooted out and burnt and carbon disulphide injected at the rate of 200–400 gm./sq. m. The details vary considerably; the treatment became far less drastic in later years, and it is rarely employed now.

The more common method of control, of applying lower rates (24–40 gm./sq. m. in four injections) of carbon disulphide to kill the *Phylloxera* without harming the stock is described by Girard (1883), Chauzit (1884) and many others. French scientific literature of that period is full of references to the chemical control of the "scourge", and these two authors are selected because their books happened to be available. More recent references are by Vermorel and Crolas (1915) and Bourcart (1926), who recommend a minimum rate of 20 gm./sq. m. applied in two, or preferably four, injections. (See also Faes, 1926; Faes and Tonduz, 1926, 1927.) Printz (1926) has also experimented with carbon disulphide for the control of *Phylloxera* in Russia, and obtained complete control with a mixture of about 1 oz. carbon disulphide and 1 oz. kerosene/sq. yd. (40 gm. of each/sq. m.). Less attention has been paid to the chemical destruction of *Phylloxera* in Europe since the introduction of resistant American stocks.

Eriosoma lanigerum, Hsm. (Woolly Apple Aphis).

Stedman (1896) tested carbon disulphide injections to control this pest. 1–3 fl. oz. (35–92 gm.) per tree in one to three injections close to the tree resulted in its death or severe injury. Leach (1920) also found it difficult to avoid injury to the roots except with very careful spacing of the injections, and even with four injections, each of ¾ fl. oz. (92 gm./tree), 6–8 ins. (15–20 cm.) deep, some Aphids near the surface always survived.

LEPIDOPTERA.

Aegeriidae.

Woodworth (1902) suggested 1 oz. (35 gm.) of carbon disulphide per tree poured around the base of peach trees for the control of the borer, *Aegeria exitiosa*, Say, but stated that in light soils the gas was dissipated too quickly to be effective, and in heavy soils it might persist so long that it would injure the tree. Becker (1918) applied 1·3 oz. (50 gm.) per tree in a furrow 4 to 6 ins. (10 to 15 cm.) from the base of the tree, and the following day found 38 dead borers and 8 live ones (all but one of which were in the trunk) in 19 trees examined. A year later, however, half the treated trees were dead, and others were unhealthy and again infested with borers.

Cossidae.

Jean (1922) controlled larvae of *Hypopta caestrum*, Hb., attacking asparagus in France by dibbling in carbon disulphide at 20–30 gm./sq. m.

Noctuidae.

Hawley (1918) carried out a large number of experiments on the control of the hop borer (*Hydroecia immanis*, Gn.) with carbon disulphide, but failed to secure satisfactory and conclusive results with one or two injections 6 ins. (15 cm.) deep with doses up to 15 cc. (19 gm.) per plant.

COLEOPTERA.

Carabidae.

Karumidze and Novitzkaya (1935) obtained complete mortality of *Zabrus tenebrioides*, Goeze, attacking cereals with the application of 2·8–3·5 oz. of carbon disulphide/10 sq. ft. (100–125 gm./sq. m.) in holes 10 ins. (25 cm.) apart and 8–12 ins. (20–30 cm.) deep.

Scarabaeidae.

White Grubs : *Lachnosterna* sp.

Vermorel (1905) recommended 30 gm./sq. m. applied to the soil between November and March to control white grubs. Headlee (1916), however, found ¾ oz./sq. ft. (292 gm./sq. m.) necessary, and Komp (1920) 1 oz./sq. ft. (388 gm./sq. m.).

Various Chafer Grubs : *Melolontha* sp., *Phyllopertha* and *Amphimallus*, etc.

Pospielov (1913) and Zvierezomb-Zubkovsky (1914) recommended 35–40g m./5½ sq. ft. (70–80 gm./sq. m.) ; Chigarev (1932) obtained 91% kill with 60 gm. injections 20 ins. (50 cm.) apart (240 gm./sq. m.); Faes and Staehelin (1923) found 150–200 gm./sq. m. effective in fallow ground for larvae more than 15 cm. deep ; the maximum dose tolerated by plants (80 gm./sq. m.) did not control the grubs. In an anonymous communication (Forestry Commission, 1927), 7–12 injections per square yard each of 5 gm. (42–71 gm./sq. m.) were suggested. Krasnyanskiĭ (1937) obtained complete mortality with 20 gm. injections, 20 ins. (50 cm.) apart (80 gm./sq. m.) ; Regnier (1939) found 70 gm./sq. m., placed in five holes 10 cm. deep, necessary to kill larvae of *Amphimallus majalis*, Raz. To make the disulphide easier to handle he advised adding 20% of carbon tetrachloride. Köbelin (1927) recommended the application of 40 cc. per hole between vine stocks in the spring to control chafer larvae attacking vines. Printz (1932) obtained a complete kill of *Polyphylla olivieri*, Lap., attacking vines with 3·6 oz./sq. yd. (120 gm./sq. m.) applied in October. Hengl (1935), using carbon disulphide at 300 gm./sq. m., prevented Melolonthid attack on vines without harming them. In strawberry beds 400 gm./sq. m. was successful though expensive. Ripper (1935) advised 5 cc. (6 gm.) per plant in May and 9 cc. (11 gm.) per plant in June applied to sugar-beet immediately the plant showed signs of injury by chafer larvae.

North American Grass Grubs : *Popillia japonica*, Newm., *Anomala orientalis*, Waterh., *Aserica castanea*, Arr.

The official instructions of the U.S. Department of Agriculture (1929, 1939 *b*) for the control of these grubs in plant beds are 21 cc. injections in holes 12 ins. (30 cm.) apart and 1–2 ins. (2·5–5 cm.) deep (290 gm./sq. m.). The soil temperature must be over 45° F. (7° C.) at a depth of 6 ins. (15 cm.). The same recommendations are made by Hamilton (1940), who also suggested applying the fumigant in furrows 10 ins. (25 cm.) apart, and Fleming and Baker (1930), who also specify 1 lb. per cu. yd. (600 gm./cu. m.) for fumigating potting soil in bulk. Each 18-ins. (45 cm.) layer should be treated separately and another layer filled in on top and treated similarly. The fumigation should be done in a gas-tight box or tank which should not be opened for 48 hours. This same rate had previously been recommended by Howard (1922).

Sugar-cane Grubs.

Jarvis (1929), in a review of Australian methods of controlling cane grubs (*Dermolepida albohirtum*, Waterh.), stated that 77 lb./ac. (9 gm./sq. m.) applied in holes about 3 ins. (7·5 cm.) deep resulted in kills of 70–95%. Previously (1923, 1927 *a*) he had recommended this application in ½-oz. (18 gm.) doses 15 ins. (38 cm.) apart, and 6 ins. (15 cm.) from the centre of the stool and on both sides. In 1932 he recorded a kill of 86% from one district and claimed that failures of the treatment that had been reported must be due to faulty application. Mungomery (1931) obtained 71% kills of grubs of *Pseudholophylla furfuracea*, Burm., with injections of 4·8 cc. (6 gm.) on either side of the stool. This caused a slight wilting of the plant, but it soon recovered. Swezey (1913), in Hawaii, recorded 95–99% kills of *Anomala orientalis*, Waterh., with 10 and 20 cc. injections every 10 ins. (25 cm.) of cane row. This was equivalent to 75–150 U.S. gals./ac. (109–218 gm./sq. m.). On the other hand Cotton (1918) in Porto Rico reported injury to canes at rates of insecticidal value.

Odontria zealandica, White (New Zealand Grass Grub).

Green (1913) found ¼ oz. (7 cc.) injections every 3 ft. (8 gm./sq. m.) sufficient to control the grub in lawns and gardens. Cottier (1932) recommended 15 and 21 cc. injections in holes 12 ins. (30 cm.) apart (200–290 gm./sq. m.). The grass was killed by this treatment within an inch or so of the hole.

Various Scarabaeid Larvae.

Leefmans (1915) obtained complete mortality of Cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.) with 40 and 50 cc. (50 and 63 gm.) per plant applied in holes 20 cm. deep. Otanes (1924) advised 1–4 cc. (1·5 gm.) of carbon disulphide in holes 3–4 ins. (7·5–10 cm.) deep, and 15–20 cm. from the base of the plant for the control of root grubs (*Leucopholis irrorata*, Chevr.) attacking seedlings in the Philippines. Nichol (1935) obtained 90% control of larvae of the fig beetle (*Cotinis texana*, Casey) in Arizona by applying half a teaspoonful of carbon disulphide to each larval tunnel.

Elateridae.

Comstock and Slingerland (1892) record an experiment in which they used 5 cc. doses of carbon disulphide, but the area over which these were effective was not stated. Subklew (1938) lists many early workers who used it with success to control wireworms. Umnov (1913) applied it in four holes in a box experiment at 30 gm./sq. m. and only obtained 33% kill of wireworms after 24 hours. Marlatt (1929) obtained approximately 100% kill of wireworms with doses of 1 fl. oz. in holes 4 ins. (10 cm.) deep and 18 ins. (45 cm.) apart (175 gm./sq. m.). The best results were achieved when the soil was uniform and loose in texture, the moisture content less than 10%, and the temperature above 50° F. (10° C.). Later (1931), he reported that this treatment was effective to a depth of 18 ins. (45 cm.). A similar rate was recommended by Lane and Gibson (1932).

McDougall (1934) obtained negative results in the control of the sugar-cane wireworm (*Lacon variabilis*, Cand.) with carbon disulphide applied near the sets about the time of attack at 350 lb./ac. (39 gm./sq. m.). Vershinskaya (1932) obtained complete kills of wireworms buried in cages 4–20 ins. (10–50 cm.) deep with carbon disulphide applied in five holes per sq. m. at 250–300 gm./sq. m. After 24 hours it was only effective below 8 ins. (20 cm.), and it ceased to be effective at all after five days. Morrill and Lacroix (1938) found ¼–½ oz. (9–18 gm.) drilled into the soil near newly set out tobacco plants killed both the plants and the wireworms (*Pheletes ectypus*, Say) which were attacking them. Wilson (1940) obtained complete mortality of wireworms (probably *Melanotus communis*, Gylh.) in plot experiments with an application of 1383 lb./ac. (155 gm./sq. m.) and afterwards covered with a tarpaulin for 48 hours.

Curculionidae.

Grandi (1916) recommended 30–50 cc./sq. m. (39–65 gm./sq. m.) after the crop had been removed to control larvae and pupae of *Tychius quinquepunctatus*, L.

Feytaud (1918) obtained good control of the vine weevil (*Otiorrhynchus sulcatus*, F.) with four injections, each of 5–7 gm./sq. m. (20–28 gm./sq. m.), but the treatment was very expensive. Haupfleisch (1933) also destroyed these larvae at the roots of yew trees with 22–25 cc./sq. m. (27–32 gm./sq. m.). F. F. Smith (1932), however, stated that carbon disulphide was useless to control this pest except at rates that killed cyclamens and primulas.

French and Hammond (1926) found 1 oz. in each of five holes per apple tree (180 gm./tree) ineffective for the control of the apple borer, *Leptops hopei*, Fhs.

Vasina (1927 *b*) recorded only four beetles emerging from 30 pupae of *Ceuthorrhynchus quadridens*, Panz., in soil treated with carbon disulphide soaked in five cotton-wool balls each placed 4–5 cm. from the cocoons in a laboratory experiment. Nevskiĭ (1929) obtained only 15% kill of pupae and young adults, and less of larvae, of *Rhynchites auratus*, Scop., subsp. *ferganensis*, Nevsk., a pest of apricot trees, with applications of 10½ oz./sq. ft. (3,200 gm./sq. m.). Pussard and Nepveu (1939) successfully controlled the larvae and adults of *Rhytidoderes plicatus*, Ol., attacking cauliflower roots in Southern France, with 300 gm./sq. m., making two injections per sq. m.

Schwardt and Lincoln (1940) found 36 cc. injections 15 ins. (38 cm.) apart and 6 ins. (15 cm.) deep (400 gm./sq. m.) killed all larvae and adults of the alfalfa snout beetle (*Otiorrhynchus ligustici*, L.). Strong (1940) stated that carbon disulphide at 11 cc./sq. ft. (150 gm./sq. m.) gave the most effective control of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) in plots of ground-nuts, provided plant injury was not objected to. All larvae were killed to a depth of 16 ins. (40 cm.). For disinfesting potting soil from this insect and *P. peregrinus*, Buchanan, the U.S. Department of Agriculture (1941) specifies the use of 2 lb. carbon disulphide per cu. yd. for 48 hours in a closed container (1,200 gm./cu. m.).

Chrysomelidae.

Scammell (1915) found injections of ½ fl. oz. 12 ins. (30 cm.) apart and 4 ins. (10 cm.) deep (193 gm./sq. m.) ineffective for the control of the cranberry rootworm (*Rhabdopterus picipes*, Oliv.). He attributed the failure to the wetness of the ground. Feytaud (1932) stated that 500–750 l./ha. (63–95 gm./sq. m.) injected into the soil 8 or 20 cm. deep (preferably the latter) gave very satisfactory results in the control of all stages of the Colorado beetle (*Leptinotarsa decemlineata*, Say).

Cerambycidae.

It was recommended (Anon. 1913) that 7-gm. doses should be injected 25 cm. from grape vines in winter to control grubs of *Vesperus xatarti*, Muls., attacking the stocks. Several repetitions of the treatment might be necessary. Satisfactory control of this insect (Anon. 1926) has been obtained in vineyards with injections of carbon disulphide at 200 kg./ha. (20 gm./sq. m.).

MYRIOPODA.

Scutigerella immaculata, Newp. (Glasshouse Symphylid).

Riley (1929) found 1-oz. injections 12 ins. (30 cm.) apart (385 gm./sq. m.) gave effective control of this pest. Better still was carbon disulphide vapour forced into the soil under pressure. Filinger (1931 *b*) also reported successful results with injections 4 ins. (10 cm.) from the plant rows, and on both sides, at the rate of 4 lb./150 ft. of row (40 gm./m.). Michelbacher (1932) obtained complete mortality in small plots with injections at the rate of 145 and 290 U.S. gals./ac. (175 and 350 gm./sq. m.).

MISCELLANEOUS.

Bernès (1914) recommended carbon disulphide at 10 gm. per hole at intervals of 50 cm. (40 gm./sq. m.) to control *Melolontha* grubs and mole-crickets (Gryllids) in fallow soil. Rolet (1914), in a general paper on the use of carbon disulphide as a soil fumigant, advised 40 gm./sq. m. in compact soils and 30 gm./sq. m. in light soils. For special purposes, rates varying from 20 to 380 gm./sq. m. might be necessary. In an anonymous paper (Bogotá, 1916) 30 gm./sq. m. was recommended for the control of various soil pests, *Oniscus*, *Iulus*, *Margarodes*, etc. Willaume (1931) advised 30–60 gm./sq. m. for soil with growing plants and 150–300 gm./sq. m. for fallow soil.

Summary.

The recommended rates of application vary between 20 and 400 gm./sq. m. Quite a high proportion of successful results have been recorded between 20 and 40 gm./sq. m. for insects other than Coleopterous larvae. For these, rates in the region of 300 gm./sq. m. appear to be necessary, though some workers have obtained high kills with lesser amounts.

(b) *Carbon Disulphide applied as an Aqueous Solution, Emulsion or Suspension.*

The use of carbon disulphide in this form has been largely developed in America. The object is to secure a better penetration and a more uniform distribution than is obtained with single-point injections of the neat substance. For small areas it can be watered on with a watering can, but for larger areas spraying apparatus is necessary, and the quantities of water required create a serious problem. Nevertheless, carbon disulphide is probably more generally recommended and used in this form now than by injection.

The earliest workers (Molz, 1911; Leach, 1918) used aqueous suspensions in which the carbon disulphide was agitated vigorously in order to prevent it settling out. The first reference to the use of an emulsion appears to be by an anonymous author (Barbados, 1914), who suggested adding castor or cotton-seed oil and an alkali (1½ oz. sodium carbonate/gal.), as emulsifying agents. Later improvements have been very largely due to Fleming and his co-workers, and much of the following information is derived from the review of Fleming and Baker (1935).

Carbon disulphide can be easily emulsified, and soap is one of the most useful agents. Emulsions made with commercial soaps, however, tend on long standing or exposure to low temperatures, to separate into three layers soap solution, emulsion and pure carbon disulphide, and it is impossible to reconstitute these by agitation. To overcome this difficulty, Lipp (1927) used a sodium oleate-rosin emulsifier which gave a more stable emulsion except at low temperatures. The formula was as follows: 50 gm. rosin, 50 cc. oleic acid, 135 cc. 7% sodium hydroxide, and 450 cc. water. The rosin is pulverised and added gradually to the previously warmed alkali solution until dissolved. The oleic acid is then added and the mixture agitated. After cooling, three parts of this mixture is added to seven parts of carbon disulphide and again agitated. This formula has proved very useful in the large-scale treatment of grasslands in America for the control of the Japanese beetle and similar pests.

Miscible Carbon Disulphide.

Miscible carbon disulphides are stable under a wider range of environmental conditions than stock emulsions. They are prepared by adding a certain quantity of alcohol or phenol to keep soap in solution when mixed with carbon disulphide. Increasing the alcohol beyond a certain point tends to prevent proper dispersion of the chemical when the mixture is added to water. Fleming and Baker (1935) gave a number of different formulae, of which no. 10 seemed to have the most satisfactory properties for use in commercial nurseries. Their description, specification and method of preparation are given almost verbatim.

It is a mobile, translucent liquid with a specific gravity of 1·555 at 15°/4° C. It does not form a heavy foam when shaken, can be poured easily, and measured accurately in small quantities. It remains homogeneous for at least several months under normal conditions, and it mixes easily with water in all proportions, forming a milky emulsion.

Formula No. 10.

	Parts by volume
Carbon disulphide	1
Alcoholic soap solution	1
the latter consisting of:	
Blown castor oil	832 gm.
Potassium hydroxide	37 ,,
Denatured alcohol	86 ,,
Water	45 ,,

The castor oil should have a specific gravity between 0·991 and 1·004 at 15° / 4°C; an iodine number between 205 and 216; fatty acids between 63 and 53, and an acid value between 210 and 225. The alcohol should have been denatured according to formula 1 of the Bureau of Internal Revenue of the U.S. Treasury Department, and should contain 10% by volume of methanol and 0·5% benzene. It should be 190 proof. The potash should be at least 80% pure, containing only traces of sulphates, chlorides, nitrates and silicates, and should be soluble in alcohol.

Preparation. In preparing the soap solution an excess of potassium hydroxide is dissolved in a mixture of seven parts by volume of alcohol and three parts of water. Aliquot samples of the solution are standardised against normal hydrochloric acid and sufficient alcohol and water added to obtain a concentration of 24·5–25 gm. potassium hydroxide in 100 cc. Then 10 parts of the alcoholic potash are mixed with 55 parts by volume of castor oil and heated in a closed kettle with constant agitation until the temperature of the mixture has been at 200° F. for two hours. When this is completed, it should have the following composition by weight:—

	%
Non-volatile constituents:	
Castor oil	83·2
Potassium hydroxide	3·7
Volatile constituents:	
Alcohol	8·6
Water	4·5

When the soap has cooled, it is mixed with an equal volume of carbon disulphide and agitated until the mixture is homogeneous.

Fleming and Baker also recorded evidence to show that certain emulsifying agents affected the degree of toxicity to Japanese beetle larvae. The rate of evaporation of carbon disulphide from emulsions also appeared to be influenced by the emulsifier and by the relative proportions of it and the disulphide. To what extent carbon disulphide applied in the form of an emulsion acts as a gas in the soil and to what extent as a contact insecticide does not appear to have been investigated.

The Penetration of Emulsions into the Soil.

As would be expected, the soil exerts a certain "filtering" action on emulsions, resulting in a high concentration in the surface layer. Fleming and Baker (1935) are the only workers who have investigated this problem intensively, and they found that the depth of penetration depended very much on the type of soil. In highly absorptive soils, such as peat, the maximum penetrations of lethal quantities of carbon disulphide was 1–3 ins. In sandy soils there was comparatively little absorption of the carbon disulphide. In such soils a high proportion of fumigant could be recovered, whereas in clay soils, or soils containing much organic matter, a certain amount of fumigant appeared to become bound up and not available. If such soils were treated again, a much higher proportion of carbon disulphide could be recovered, suggesting that there was a saturation point.

Under favourable conditions in the field, however, they obtained complete kills of Japanese beetle larvae at various depths, using the following amounts of liquid:—

Depth of larvae (ins.).	*U.S. gals./sq. ft.*	*Conc. CS_2 (mg./l.).*	*gm./sq. m.*
6	1·8	1400	103
6	2·4	1100	108
12	3·0	1225	150
18	3·0	1375	169

Lateral diffusion outside the zone wetted was negligible. The emulsion had little toxic effect when the soil temperature was below 40° F. (4° C.), and the insecticidal

action was inversely proportional to the moisture content of the soil. Treatment of clay soils when these were wet and impervious, or dry and cracked, was usually unsuccessful.

The rate of penetration, which depended upon the factors mentioned, was a good measure of the probable effectiveness of the treatment, *i. e.*, if under certain specified conditions the liquid took too short a time to disappear it would be drained away too quickly. On the other hand, if it took too long a time, penetration would not be adequate and some fumigant would be lost by evaporation from the surface.

Experiments in Soil.

ORTHOPTERA.

Gryllidae.

W. A. Thomas (1926) obtained 95% kill of the Porto-Rican mole-cricket (*Scapteriscus vicinus*, Scud.) in golf courses with a 1/400 dilution of a 75% commercial carbon disulphide emulsion sprinkled on at 2 U.S. qts./sq. ft. (50 gm./sq. m.). Reinfestation occurred after one month.

ISOPTERA.

McDaniel (1934) found $2\frac{1}{2}$ U.S. gals./sq. ft. of a standard 50% emulsion diluted to 0·12–0·18%, according to the temperature, eradicated termites in the soil (12 gm./sq. m.).

THYSANOPTERA.

Richardson and Nelson (1933) found a 1/750 emulsion applied to gladiolus corms the day after planting at the rate of 1 U.S. gal. per 50 corms was ineffective for the control of *Taeniothrips gladioli*, Mlt. & Stnw.

HEMIPTERA.

Cicadidae.

Wilson (1930) found a 1/8 dilution of a 70% stock emulsion applied at 3 U.S. pints/sq. ft. (1790 gm./sq. m.) gave good control of fourth-instar nymphs, but had no effect on fifth-instar nymphs of *Tibicen davisi*, Smith & Grosbeck.

Aphidae.

Leach (1918) was able to control woolly apple aphis (*Eriosoma lanigerum*, Hsm.) under suitable soil conditions with a solution prepared by vigorously agitating $\frac{1}{2}$ oz. carbon disulphide in 4 U.S. gals. water and applied at $\frac{3}{4}$ U.S. gals./sq. ft. (37·5 gm./sq.m.). It had no harmful effect on the trees, though at higher rates they were killed or their growth checked. Marcovitch (1934) found $\frac{1}{2}$ U.S. pint of a stock emulsion diluted to 1/50, or $1\frac{1}{2}$ pints diluted to 1/200, applied to apple trees resulted in the disappearance of the Aphids. Both authors found the treatment too expensive for commercial use. Underhill and Cox 1940) obtained satisfactory control of this insect with carbon disulphide diluted to 1/1,600 and applied at 1.U.S. gal./sq. ft. (33 gm./sq. m.) without injury to the apple tree. At higher rates the roots were scorched or the tree killed.

LEPIDOPTERA.

Aegeriidae.

Howard (1918 and 1919) stated that 95 to 100% kill of peach tree borers (*Aegeria exitiosa*, Say) was obtained with $\frac{1}{8}$ to $\frac{1}{4}$ oz. (4–9 gm.) carbon disulphide applied to peach trees in 1 U.S. gal. water. Headlee and Ilg (1926) were able to kill larvae of the raspberry crown borer (*Pennisetia marginata*, Harr.) with $2\frac{1}{2}$ fl. oz. of a 70% stock emulsion previously diluted with rather more than an equal quantity of water. Complete kills were also secured with smaller amounts, but the results were not consistent. Pupae were more resistant than the larvae.

Noctuidae.

Cory (1928 *b*) obtained a high kill of pupae of the iris borer (*Macronoctua onusta*, Grote) without injuring iris plants with 2·5 and 5 cc. of a 70% emulsion in 1 U.S. gal. applied at 1·8 U.S. gal./sq. ft. (87 gm./sq. m.).

Crambidae.

Noble (1932) found a 0·05% emulsion applied at 1 U.S. gal./sq. yd. (3 gm./sq. m.) was ineffective for the control of sod web-worms in lawns and golf greens. Stone and Elmore (1937) obtained a 50% kill of *Crambus* sp. in lawns with an emulsion of 4½ oz./10 U.S. gals. applied at 1 U.S. gal./sq. yd. (20 gm./sq. m.).

COLEOPTERA.

Scarabaeidae.

North American Grass Grubs: *Popillia japonica*, Newm., *Anomala orientalis*, Waterh., *Aserica castanea*, Arr.

Leach and Thomson (1921) found saturated solutions and 3% emulsions of carbon disulphide gave poor control of Japanese beetle larvae in artificial soil balls, though the results obtained from dipping the naked larvae in them had been promising. They attributed the failure to the filtering action of the soil. Leach and Johnson (1925), however, found half-saturated and saturated solutions of carbon disulphide watered on the roots of potted plants gave complete mortality of these grubs. The plants were checked somewhat.

For the adults, Fleming (1926) found solutions of 0·75 and 1·375 cc./l. watered on to the soil in pots gave complete mortality in periods varying from 6 to 30 hours. This concentration was fatal to *Salvia* and *Nasturtium* plants. For the control of the larvae in golf greens, Leach and Thomson (1923) recommended 500 cc. of a stock 70% emulsion diluted to 50 U.S. gals. and evenly watered on at ½ U.S. gal./sq. ft. (50 gm./sq. m.). The same formula was recommended by Zappe and Garman (1925) for the control of larvae of *Anomala orientalis*, Waterh. Their rate of application was about 64 gm./sq. m. They also found 59-139 cc./sq. m. of an unspecified emulsion was effective. Britton and Zappe (1926), however, obtained unsatisfactory results with a presumably similar emulsion applied at the rate of 69–139 cc./sq. m. Johnson (1927) reported 98% kill of Asiatic beetle larvae (*Aserica castanea*, Arr.) with the treatment of grassland on a large scale with an emulsion at a rate equivalent to about 67 gm. carbon disulphide/sq. m.

Cory and Sanders (1929) and Friend (1929) for the control of *P. japonica* and *A. orientalis*, respectively, advised a 1/200 dilution of a 70% emulsion applied at 3 U.S. pints/sq. yd. (70 gm./sq. m.). Cory and Sanders specified two applications, though even these might not be sufficient on very hard and heavy soils. The same rate was recommended by L. B. Smith (1929) in a general review on the control of *P. japonica*. He stated that the emulsion was not effective below 3–4 ins. (7·5–10 cm.) and that the soil temperature must be above 40° F. (4° C.).

Fleming and Baker (1930 and 1935) have described methods of localising the action of liquid soil insecticides by the use of galvanised iron collars sunk about 3 ins. (7·5 cm.) into the soil around infested plants. The U.S. quarantine authorities have recognised this method and (U.S. Dep. Agric. 1932) specify 45–68 cc. (according to the temperature) of a 50% emulsion diluted to 10 U.S. gals. and applied at the rate of 2½ U.S. gals./sq. ft. (78–118 gm./sq. m.). If the liquid takes less than 10 minutes or more than five hours to disappear, the treatment cannot be considered successful.

White grubs: *Lachnosterna* sp.

It was stated in an anonymous paper (Porto Rico, 1924) that 90–100% kill was obtained with an emulsion as described by Leach and Thomson (1923) (see preceding section). It was applied at a slightly higher rate equivalent to 60 gm./sq. m. Dozier (1926) obtained a 75% kill of *L. portoricensis*, Smyth, with 75 cc.

of an unspecified emulsion diluted to 7½ U.S. qts. and applied to 12¼ sq. ft. (65 cc. emulsion/sq. m.). Garman (1936) found ½, 1 and 2% dilutions of a 67% emulsion were ineffective for the control of larvae of *L. fusca*, Froel., damaging seedling fruit trees. A coconut-oil-soap emulsion of ¾ oz. carbon disulphide/gal. applied to infested sugar-cane stools at the rate of ¼ gal. per plant (9 gm. carbon disulphide) was recommended anonymously (Mysore, 1937) to control *L. serrata*, F., and other white grubs attacking sugar-cane and other plants. See also Komp (1920).

Various Scarabaeid Larvae.

Lamborn (1914) successfully controlled a Lamellicorn beetle damaging plant roots in Nigeria with carbon disulphide diluted to 1/200. Downes (1928) obtained 50% kill of *Aphodius pardalis*, Lec., damaging lawns in British Columbia with an emulsion of 3 oz. carbon disulphide in 3 gals. water. The treatment caused considerable burning of the grass.

Cottier (1932) found 0·14 pints of a 70% emulsion applied to one square yard in 31 pints of water (85 gm./sq. m.) gave economical control of the New Zealand grass grub (*Odontria zealandica*, White), but caused some burning of the turf. This injury was reduced by using a proprietary weed exterminator as an emulsifying agent. Jewett (1937) obtained only 30% kill of *Cotinis nitida*, L., larvae with 1·4 U.S. qts .of carbon disulphide diluted in 100 U.S. gals. of water and applied at 2 U.S. gals./sq. yd. (40 gm./sq. m.). Tobacco plants were also injured by the treatment.

Elateridae.

Britton and Anderson (1926) reported that carbon disulphide-soap emulsions at 1/720 failed to kill tobacco wireworms (*Pheletes ectypus*, Say), and at 1/360 killed the plants. Headlee (1931) found 1 oz. (29 cc.) of carbon disulphide emulsified in 1 U.S. qt. of water and applied to maize hills through a galvanised iron cone gave high kills of wireworms. Stone and Campbell (1933) found carbon disulphide solutions and emulsions were only about one-third as effective for the control of *Pheletes californicus*, Mannh., as chlorpicrin (*q.v.*) applied in the same way. For the same species, Lacroix (1934) obtained inconclusive but apparently unsuccessful results with a 1/200 emulsion applied in furrows 3 ins. (7·5 cm.) deep at 1 U.S. qt./2 ft. (10 gm./m.). Speyer *et al.* (1940) found an emulsion applied to tomatos at rates equivalent to 15 oz. carbon disulphide/sq. yd. (650 gm./sq. m.) killed wireworms (probably *Agriotes* sp.), but was injurious to young plants. Gough (1942) found 2–4% emulsions applied at the rate of 2 gals./sq. yd. (287–574 gm./sq. m.) gave high kills of *Agriotes* sp. in pot experiments.

Curculionidae.

Whitcomb (1929) recorded 90 and 99·5% kills of larvae and pupae of the plum curculio (*Conotrachelus nenuphar*, Hbst.) in the soil with 2 and 3 U.S. pints/sq. ft. respectively (50 and 75 cc. emulsion/sq. m.) of a ½% dilution of a carbon disulphide emulsion. McDaniel (1932) found the formula recommended by the U.S. Department of Agriculture (see under "American Grass Grubs") at 78–118 gm./sq. m. effective for the control of the strawberry root weevil (*Otiorrhynchus ovatus*, L.) attacking conifer seedlings. The application should be made after the seedlings have been removed. F. F. Smith (1932), however, obtained inconsistent results with such emulsions in the control of larvae of the black vine weevil (*O. sulcatus*, F.), and no control at concentrations tolerated by the host plants. Lovell (1932) also reported unsuccessful results in the control of larvae and pupae of the vegetable weevil (*Listroderes obliquus*, Gylh.) at concentrations up to 60 cc. of a 50% stock emulsion/U.S. gal. Hoerner (1936) obtained 70–100% kill of larvae of the western rose curculio (*Rhynchites bicolor wickhami*, Ckll.) with applications to the soil of an emulsion containing 0·35% carbon disulphide at 1 U.S. qt./sq. ft. (50 gm./sq. m.). Rose bushes were not damaged. English and Graham (1938) obtained 73–97% kills of larvae

of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) with 5 U.S. gals. of an emulsion containing 3·3–5·7 cc. carbon disulphide per gal. applied to the soil in iron hoops 18 ins. (45 cm.) in diameter for 24 to 72 hours exposure (130–225 gm./sq. m.). Broudy (1935) recorded a high kill of grubs of Fuller's rose beetle (*P. godmani*, Crotch) attacking roses in a greenhouse with a carbon disulphide emulsion sprayed on to the soil.

Chrysomelidae.

Feytaud (1932) stated that carbon disulphide emulsions applied to the soil at the rate of 100 gm./sq. m. were useless for the control of Colorado beetle (*Leptinotarsa decemlineata*, Say).

DIPTERA.

Trypetidae.

Rhagoletis cerasi, L. (Cherry Fruit-fly).

Wiesmann (1933, 1934) found 5 l. of 1½ and 3% emulsions/sq. m. (75 and 150 cc. cm./sq. m.) were ineffective for the control of larvae in the soil. Thiem (1934) also found 50 cc. of a 16 % emulsion applied to cages ⅐ sq. m. in area (70 gm./sq. m.) ineffective.

Buckhurst (1937) reported promising results in the destruction of overwintering pupae of the asparagus fly (*Platyparea poeciloptera*, Schr.) with carbon disulphide emulsions.

HYMENOPTERA.

Andrenidae.

Sanders (1928) obtained almost complete control of a solitary bee (*Andrena perplexa*, Smith) burrowing in lawns with 1 U.S. pint/sq. ft. of a 70% stock emulsion diluted to 1/200 (23 gm./sq. m.). Walker and Anderson (1937) found ½ and 1% dilutions of a 66·7% emulsion had no effect on the pavement ant (*Tetramorium caespitum*, L.) attacking egg-plants. The higher rate injured the plants.

MYRIOPODA.

Scutigerella immaculata, Newp. (Glasshouse Symphylid).

Filinger (1931 *b*) found surface applications of emulsions of 1, 2 and 3 U.S. qts., 50 U.S. gals. water were useless. Michelbacher (1932) only obtained an average kill of 26% (the individual results being somewhat inconsistent) with a 65% stock emulsion diluted to 1/300 and applied at 5 U.S. gals./sq. yd. (63 gm./sq. m.). Brunetau (1935) also obtained inconclusive results at a much lower rate (18 gm../sq. m.). Herrick (1927) reported that a 1% miscible solution of carbon disulphide used for drenching earth just brought in for greenhouse soils appeared to cause a 100% reduction of the centipedes.

Lack of penetration into the subsoil, where the Symphylids are frequently to be found, may have accounted for the ineffectiveness of emulsions, and Miles and Cohen (1935) obtained good control by the application of 1 gal./sq. yd. of a 1/60 emulsion to the subsoil (117 gm./sq. m.) and a surface application at 2 gals./sq. yd. of a 1/100 emulsion (140 gm./sq. m.) before planting tomatos. If the soil could not be treated before planting, three applications of a 1/120 emulsion at weekly intervals at the rate of ½ pt. per plant were advised.

SUMMARY.

Emulsions watered on to the soil so that 50–100 gm./sq. m. of carbon disulphide is applied appear to have given good results in the control of most soil pests, and they thus appear to be rather more economical in material than injections of the pure substance.

The Addition of other Substances to Carbon Disulphide Emulsions.

Naphthalene (see p. 61).
p-dichlorbenzene (see pp. 47–48).
Pyrethrum (see p. 128).

Miles and Cohen (1939) tested the following substances in carbon disulphide emulsions as possible soil insecticides for the control of wireworms (*Agriotes* sp.), all without success: dimethylaniline, diphenylamine, quinoline.

Chlorpicrin (CCl_3NO_2).

Liquid. S.G. 1·692 at 0° C.

Chlorpicrin came into use as an insect fumigant after the 1914–1918 war. It has also proved successful as a soil insecticide, but is inconvenient to handle, and for that reason has not become popular.

Higgins *et al.* (1939) have described a method for the determination of small quantities of chlorpicrin in fumigated soil.

Effect on Vegetation and Micro-organisms.

According to Marumo (1930), Lacroix (1934) and Emel'yanova (1938) it is toxic to plant life. On the other hand, Savchenko and Pal'chik (1935) and Schwardt and Lincoln (1940) only record slight injuries to plants. Stark *et al.* (1939) stated that low doses had little effect on nitrate formation in the soil, but as the dosage was increased, nitrification was inhibited. In no case, however, was ammonification inhibited.

Application.

Chlorpicrin can be used either in a more or less pure form, in water as an emulsion, or absorbed in solids. In view of its toxicity to man, special precautions must be taken in its application, and it may be necessary for the operators to wear respirators.

Hasson (1920) describes its application by a special apparatus comprising a container and an air pump worked off the wheels of the plough on which the apparatus was mounted. The liquid was sprayed at the rate of 1 litre per minute into the preceding furrow and the sod of the next furrow turned over it. The amount applied per acre in this way was not stated, but all soil pests, including wireworms, were killed.

Gaumont (1927) made experiments in which the chlorpicrin was poured into a system of pipes 35–40 cm. deep, and its toxic vapour carried into the soil by means of a compressed air apparatus. The piping consisted of two planks nailed in a V and covered by wire netting. 80 cc. chlorpicrin in a drain 6 m. long killed cockchafer (*Melolontha* sp.) larvae placed directly above it, but not those in lines 30 cm. to each side. Another effective means of application cited by him was the absorption of the liquid in peat blocks each containing 10 cc. of chlorpicrin and enclosed in parchment.

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic (2).

Lehman (1933) recorded the median lethal dose to the wireworm (*Pheletes californicus*, Mannh.) as 0·69 mg./l. for a five-hour exposure and 45·9 times as toxic as carbon disulphide.

Thalenhorst (1937) recorded the minimum lethal dose to third-instar larvae of the cockchafer (*Melolontha hippocastani*, L.) as 5 mg./l. for a 24-hour exposure and 52·4 times as toxic as carbon disulphide.

Experiments in Soil.

(*a*) Applied pure or absorbed in Solids.

HEMIPTERA.

Aphidae.

Emel'yanova (1938) stated that 1·2 oz./sq. yd. (40 gm./sq. m.) gave complete control of the root aphis (*Xerophilaphis scorzonerae*, Mordv.) in a plantation of *Scorzonera tau-saghyz*, a rubber-producing plant in the Ukraine. The plants were, however, seriously injured.

COLEOPTERA.

Scarabaeidae.

Wolters (1934) recorded 52 and 68% kills of Oriental beetle larvae (*Anomala orientalis*, Waterh.) with chlorpicrin applied at the rate of 200 lb./ac. (22 gm./sq. m.). In a friable soil, a kill of 95% was obtained. Hamilton (1940) also obtained a satisfactory kill of these grubs in fallow soil at 2 cc./sq. ft. (36 gm./sq. m.) injected 4–5 ins. (10–12 cm.) below the surface. Sawa (1936) found chlorpicrin about fifteen times as effective as carbon disulphide to first-instar larvae of *Anomala rufocuprea*, Motsch., and about five times as effective to third-instar larvae.

Elateridae.

McDougall (1934) found chlorpicrin unsatisfactory for the control of *Lacon variabilis*, Cand., in Queensland sugar-cane fields. Savchenko and Pal'chik (1935) obtained a complete kill of wireworms (*Limonius aeruginosus*, Ol., and *Corymbites latus*, F.) with chlorpicrin applied at 60 gm./sq. m. in holes 4–10 ins. (10–25 cm.) deep at the corners of small plots. Most of the weeds were also killed, but the plants recovered and produced a normal yield. Ladell (1938) used a solid preparation containing chlorpicrin in the form of pellets at 245 lb./ac. (27 gm./sq. m.), which gave a 33% kill of wireworms (*Agriotes* sp.) in a field experiment. A similar experiment with the poison absorbed on Kieselguhr, gave a 45% kill when applied at 224 lb./ac. (25 gm./sq. m.).

Wilson (1940) applied chlorpicrin dissolved in 96% alcohol to seed-beds at 600 lb./ac. (67 gm./sq. m.) applied in holes 3 ins. (7·5 cm.) deep and 6 ins. (15 cm.) apart. The beds were covered with a heavy tarpaulin for 48 hours after treatment, and wireworms (*Melanotus communis*, Gylh.) previously buried in cages in the soil were all killed.

Curculionidae.

French and Hammond (1926) reported that 6 oz. (100 gm.) applied in a hole near an infested tree was not effective in controlling the apple root borer (*Leptops hopei*, Fhs.). Korab *et al.* (1936) obtained complete mortality of the beet weevil (*Cleonus punctiventris*, Germ.) in beet fields by injecting chlorpicrin at 14 ins. (35 cm.) intervals at 900 and 450 lb./ac. (100 and 50 gm./sq. m.) in six and 14 days respectively. The treatment was less effective in moist soil. According to Pussard and Nepveu (1939), chlorpicrin at 20 cc. (33 gm.)/sq. m. was ineffective in controlling the weevil (*Rhytidoderes plicatus*, Ol.), which was attacking the roots of cauliflowers in France. Schwardt and Lincoln (1940) injected chlorpicrin into the soil in lucerne plots to control adults and larvae of the alfalfa snout beetle (*Otiorrhynchus ligustici*, L.). 400 lb./ac. (45 gm./sq. m.) applied in holes 15 ins. (38 cm.) apart and 6 ins. (15 cm.) deep at 3 cc./hole killed 88·5% of the larvae after six days. In a similar experiment only 31·5% of the larvae were killed, though all the adults were. No injury was caused to the lucerne.

Chrysomelidae.

Feytaud (1932) stated that soil injection at the rate of 750–1000 l./ha. (127–169 gm./sq. m.) caused a high mortality of the Colorado beetle (*Leptinotarsa decemlineata*, Say).

MYRIOPODA.

Michelbacher (1932) applied chlorpicrin to small plots at the rate of 280 lb./ac. (31 gm./sq. m.) and obtained a 54% kill of the glasshouse Symphylid (*Scutigerella immaculata*, Newp.).

(*b*) Applied as an Emulsion.

COLEOPTERA.

Scarabaeidae.

Arnaud (1924) emulsified chlorpicrin with soap in water made alkaline with sodium bicarbonate ($NaHCO_3$). An emulsion of 1/200 applied at 10 l./sq. m. (85 gm./sq. m.) was effective against Melolonthid larvae attacking vines, provided the larvae were near the surface. Marumo (1930), using a soap emulsion of chlorpicrin at a dilution of about 1/200 at 18 l./sq. m. (15 gm./sq. m.), killed white grubs in turf but injured the grass.

Elateridae.

Stone and Campbell (1933) in South California obtained high kills of wireworms (*Pheletes californicus*, Mannh.) in pot experiments with a 12½% soap emulsion of chlorpicrin at about 40 gm./sq. m. They found chlorpicrin applied as an emulsion much more effective than in solution. In a field experiment 332 and 662 cc. in 100 and 200 U.S. gals. water, respectively, applied to 150 sq. m. (40 gm./sq. m.) killed all wireworms to a depth of 4 ins. (10 cm.). The chlorpicrin emulsion was applied to the water in the furrow irrigating the land. Lacroix (1934) poured an emulsion made with fish-oil soap into furrows 3 ins. (7·5 cm.) deep at the rate of 12–100 cc. emulsion to 5 l. water and obtained 100% kill of the wireworm (*Pheletes ectypus*, Say) down to a depth of 12 ins. (30 cm.) except at the weakest dilution. Wilson (1940) reported a complete mortality of the wireworm (*Melanotus communis*, Gylh.) in Florida with a soap emulsion of chlorpicrin at the rate of 300 lb./ac. (34 gm./sq. m.).

SUMMARY.

The range of application thus varies between about 20 and 100 gm./sq. m. Rates of about 50 gm./sq. m. have frequently resulted in high kills of various insects.

Coal Tar Oils and Distillates.

Coal tar products have been extensively used as insecticides and disinfectants for various purposes. They are usually classified according to the temperature at which they distil, and as the point selected is more or less arbitrary and the quality of the products depends on the type of coal, they are liable to be very variable in their constituents.

They have been grouped here under the following headings, to which they have been referred by the original author. The pure substances which form the most important constituent of each fraction are also included. The definitions of the four main fractions as given by the Joint Fuel Committee S.T.P.T.C. (1938) are as follows:

CARBOLIC ACID: A mixture of monohydric phenols of substantial phenol content.
CRESYLIC ACID: A mixture of monohydric phenols, consisting essentially of cresols and/or xylenols with or without a percentage of phenol.
CREOSOTE OIL: The oil or a blend of oils obtained from coal tar and distilling above about 200° C.
ANTHRACENE OIL: A heavy oil having a sp. gr. S 15·5° C. / 15·5° C., above about 1·080, usually distilled from horizontal retort tar or coke oven tar.

Phenol (C_6H_5OH) and Carbolic Acid.

Crystalline.

Phenol, one of the most important of the antiseptics, has been widely used as a soil sterilising agent. Except for laboratory experiments it is usually used in the crude liquid form of carbolic acid.

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic (10·6). Melander (1924), using an apparatus in which air, saturated with various chemicals, was passed through a cylinder of soil and then into an insect chamber containing bean weevils (*Bruchus* sp.), found phenol was not volatile enough to saturate the soil quickly, so that the weevils were not killed for several hours.

Fleming (1925): minimum lethal dose in air 4 mg./l.; in water 592 mg./l.

Experiments in Soil.

ORTHOPTERA.

Gryllidae.

Doucette and Smith (1926) obtained a complete kill of the Surinam cockroach (*Pycnoscelus surinamensis*, L.) in pot experiments by watering 400 gm. soil with a solution of 1 gm. phenol in 100 cc. Phenol was, however, unsatisfactory in plant beds as it injured the plants.

HEMIPTERA.

Aphidae.

Del Guercio (1917) obtained good results in the control of root Aphids by the addition of either alkaline earth or alkaline polysulphides to phenol in equal parts and using a dilution of 2–5%.

LEPIDOPTERA.

Noctuidae.

Hawley (1918) found 1 U.S. pint of carbolic acid emulsion caused some reduction in the number of hop borers (*Hydroecia immanis*, Gn.), but not sufficient to be effective. Another emulsion diluted to about 10%, used to drench the hills, gave no reduction at all.

COLEOPTERA.

Scarabaeidae.

D'Emmerez de Charmoy (1912) found a petroleum emulsion containing 1% carbolic acid used at 10 litres per stump was satisfactory in disinfesting sugar-cane ratoons from grubs of *Lachnosterna smithi*, Arr.

Fleming (1926) found phenol solution at 1 and 2 gm./l. was only partially effective as a soil dip for potted plants infested with Japanese beetles (*Popillia japonica*, Newm.).

Elateridae.

Zappe (1922) found a carbolic acid emulsion ineffective for the control of wireworms attacking tobacco plants. Gough (1942) obtained 95–100% kill of wireworms (*Agriotes* sp.) in pot experiments with phenol applied as a solid and in solution at rates equivalent to 10 cwt./ac. (126 gm./sq. m.).

Curculionidae.

Theobald (1904) found an emulsion made by adding 1 pint of crude carbolic acid to 1 gal. of water containing soft soap, and diluted to 1/30, was most successful in destroying vine weevil grubs (*Otiorrhynchus sulcatus*, F.) attacking pot plants.

F. F. Smith (1932), however, was unable to kill any of the third- and fourth-instar larvae with carbolic acid emulsions of various concentrations, and, moreover, primulas and cyclamens thus treated were severely injured.

Byturidae.

Korolkov (1913) stated that larvae and pupae of the raspberry beetle (*Byturus tomentosus*, F.) in the soil were partially destroyed by watering with about 3 l./bush of a 2% emulsion.

DIPTERA.

Anthomyiidae.

K. M. Smith and Wadsworth (1921) applied a soap emulsion containing 1 pint of carbolic acid to 1 gal. water, and diluted 1/35, to onion plots and recorded 54% of the plants not attacked by the onion fly (*Hyl myia antiqua*, Mg.).

Cabbage Root Maggot (*Hylemyia brassicae*, Bch.).

Slingerland (1894) obtained some success in the control of maggots previously placed on well established cabbages with a soap emulsion consisting of 1 U.S. pint of crude carbolic acid to 22 U.S. gals. of water (1/176). Most of the maggots were killed, but several puparia survived. Smith and Dickerson (1907) found 4–6 fl. oz. per plant of an emulsion consisting of 1 U.S. pint crude carbolic acid to a gallon of soapy water, and diluted 1/30, very effective against young maggots. MacDougall (1913) recommended a similar emulsion, diluted to 1/40, applied to the plants before the maggots entered them. Britton and Lowry (1916) also used a 1/30 dilution of a crude carbolic acid emulsion applied to cabbage at 3 fl. oz. per plant which reduced the infestation to 6%, compared with 23% in the untreated plants. Krasnyuk (1931), however, found carbolic acid emulsion was useless as a control measure for this insect.

Trypetidae.

Wiesmann (1934) obtained negative results in the destruction of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) with 5 l./sq. m. of a 3% emulsion (150 cc. emulsion/sq. m.).

ISOPODA.

Speyer and Owen (1924) found a 1/265 solution of phenol applied to soil was effective in a 24-hour exposure in killing cucumber house woodlice (*Armadillidium speyeri*, Jackson) introduced up to 52 days after treatment. 1/1000 and 1/500 solutions were effective up to two and nine days respectively.

SUMMARY.

Phenol or carbolic acid has principally been used in solution, and dilutions of ½–3% appear to have been frequently used with success. Few critical experiments have been done in recent years.

Cresol ($CH_3C_6H_4OH$) and Cresylic Acid (including Creolin, Cresolin and Lysol).

Liquid. S.G. ortho- 1·051 ; meta- and para- 1·039 at 15° C.

Cresol or hydroxy-toluene is, like phenol, usually used in its crude form, known as cresylic acid, which also contains a considerable proportion of phenol. To facilitate its dispersal in water the crude cresols are sometimes dissolved in

1. Alkalis—when the resulting liquid is known as creolin ;
2. Resin soaps— „ „ „ cresolin ;
3. Olive soaps— „ „ „ lysol.

Cresylic acid emulsions are widely used as soil sterilisers for glasshouse soils, especially in the " partial sterilisation process " (Russell (1920)). There are three isomers of cresol—ortho-, meta- and para-.

Application.

Miles (1929) and Bewley (1935) advise the application of a mixture of 1 gal. cresylic acid (97–99% pure) and 39 gals. water to 9–12 sq. yd. (600–450 gm./sq. m.) of glasshouse soil. The diluted acid is distributed over the surface so that the top inch or so of surface is well soaked. The soil is then dug in to a depth of about a foot and skimmed so that the saturated layer is placed at the bottom of the trench and its vapour slowly permeates the soil placed on top.

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic (9). Fleming (1925): minimum lethal dose in air 8 mg./l.; in water 592 mg./l.

Experiments in Soil.

HEMIPTERA.

Aphidae.

Rübsaamen (1914) used 2 l. per vine of a 10–15% cresol emulsion to disinfest areas from the vine Phylloxera (*Phylloxera vastatrix*, Planch.). Girardi (1916) recommended a surface spray of 1% cresol or lysol to kill root Aphids.

COLEOPTERA.

Scarabaeidae.

D'Emmerez de Charmoy (1912) treated sugar-cane ratoons with a petroleum emulsion containing 1% of cresolin at 10 l./stump with satisfactory results in the control of sugar-cane grubs (*Lachnosterna smithi*, Arr.). Jarvis (1916) obtained a 100% kill of cane grubs (*Dermolepida albohirtum*, Waterh.) with 1 pint creolin/50 gals. of water (1/400). Fleming (1926) found ortho-cresol at 1 and 2 gm./l. was not entirely reliable as a soil dip for potted plants infested with Japanese beetles (*Popillia japonica*, Newm.).

Elateridae.

Russell (1920) stated that cresylic acid as used in the partial sterilisation process at the rate of 280–560 gals. or 49 cwt./ac. (617 gm./sq. m.) was ineffective against wireworms.

Chrysomelidae.

Feytaud (1932) found a 10% solution of cresylic acid at 1 l./sq. m. (100 cc./sq. m.) was ineffective for the control of adults and larvae of the Colorado beetle (*Leptinotarsa decemlineata*, Say).

Byturidae.

Korolkov (1913) obtained good results in the control of larvae and pupae of the raspberry beetle (*Byturus tomentosus*, F.) with a 2% solution of creolin applied to the bushes in sufficient quantities to penetrate 4–7 ins. (10–17·5 cm.).

DIPTERA.

Psilidae.

K. M. Smith and Wadsworth (1921) found four applications of a heavy cresylic acid absorbed in sand (1/100) resulted in 70% of carrots not attacked by the carrot fly (*Psila rosae*, F.), compared with only 20% in the controls. Carrots treated similarly with a light cresylic acid were a total failure. K. M. Smith (1925) also tested ortho-, meta- and para-cresol carbonates, but found them all ineffective, though the conditions, however, were unfavourable.

Anthomyiidae.

Brittain (1922) found 0·5–1% cresylic acid (98% pure) emulsion gave little better results than the checks for the control of the cabbage root maggot (*Hylemyia brassicae*, Bch.). The following year (1923), however, he stated that it (80% cresol) was promising.

K. M. Smith (1925) obtained some, though not an effective, reduction in the number of cabbages attacked by root maggot (*Hylemyia brassicae*, Bch.) with ortho-cresol mixed with chalk (1/100). He also recorded a reduction in the number of onion plants treated with this mixture attacked by the onion fly (*H. antiqua*, Mg.). Ortho-, meta- and para-cresol carbonate (5 and 10% mixed with chalk) resulted in 19, 19 and 18% of treated plants attacked by this insect compared with 33, 31 and 23% attacked in the controls. Previously (1923) he had been able to increase the yield of onions with applications of dusts consisting of light cresylic acid absorbed in chalk.

Trypetidae.

Wiesmann (1934) obtained 93% mortality of cherry fly pupae (*Rhagoletis cerasi*, L.) with a 3% solution of cresylic acid at 5 l./sq. m. (150 cc. cresylic acid/sq. m.).

HYMENOPTERA.

Formicidae.

Corbett (1926) found an emulsion containing creolin and kerosene killed red ants (*Solenopsis geminata*, F.) damaging tobacco seedlings.

ISOPODA.

Speyer and Owen (1924) obtained 100% kill of the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) in 24 hours with ortho- and para-cresols mixed with soil at the rate of 1/231. The effectiveness was maintained for 25 and 21 days, respectively.

MYRIOPODA.

Kearns and Walton (1933) recorded good results with a cresylic acid emulsion in the control of the glasshouse Symphylid (*Scutigerella immaculata*, Newp.).

The Addition of other Substances to Cresol.

Kerosene: Corbett (1926) (see p. 103).

SUMMARY.

In spite of the fact that it is generally recommended as a useful steriliser for glasshouse soils, cresylic acid seems to be rather less successful as an insecticide than carbolic acid. Good results have been recorded at dilutions ranging from ½–10%, but frequent failures have been reported.

Creosote Oils.

Experiments in Soil.

HEMIPTERA.

Aphidae.

Del Guercio (1917) recommended an emulsion of unrefined commercial creosote as a fumigant for root Aphids and stated that better results could be secured by the addition of alkaline earths or alkaline polysulphides in equal parts and diluting the mixture to 2%–5%. Reppert *et al.* (1922) found that 1 U.S. qt. per tree of a 1/30 soluble creosote solution (30 cc. oil/tree) killed woolly apple aphis (*Eriosoma lanigerum*, Hsm.) on roots of apple nursery stock without injuring the trees. 1 to 2 U.S. qt. per tree of an 8% creosote emulsion (75–150 cc. oil/tree) caused severe injury.

COLEOPTERA.

Scarabaeidae.

According to Jarvis (1916) an emulsion of 8 oz. creosote in 5 gals. water gave fair results in the control of sugar-cane grubs (*Dermolepida albohirtum*, Waterh.). Burns (1929) used a 20% solution of commercial creosote in benzene, applying $\frac{1}{8}$ oz. both sides of the sugar-cane stools and 4 ins. (10 cm.) away, to control the same grubs. The results, though somewhat better than the controls, were inconclusive. Jarvis (1930 *a*) also recorded a 34% kill of the grubs with this mixture.

Elateridae.

Gough (1942) obtained high kills of wireworms (*Agriotes* sp.) in pot experiments with creosotes of a lower distillation range (190–280 and 220–363° C.) at rates corresponding to 10 and 15 cwt./ac. (126–189 gm./sq. m.) for a six-day exposure. A higher boiling sample (approaching anthracene oil) was less effective. The oils were absorbed in sawdust and intimately mixed with the soil.

Curculionidae.

Isaac (1923) found $4\frac{1}{2}$ fl. oz. of creosote absorbed in $4\frac{1}{2}$ lb. chalk powder and applied to a cabbage plot 1 rod in area (5 cc. creosote/sq. m.) did not appreciably reduce the number of plants galled by the weevil, *Ceuthorrhynchus pleurostigma*, Marsh.

DIPTERA.

Psilidae.

K. M. Smith and Wadsworth (1921) made four applications of creosote (1%) absorbed in sand (99%) to control infestation by the carrot fly (*Psila rosae*, F.); with a light creosote they obtained 42% uninfested carrots, and with a heavy creosote 80% uninfested carrots. K. M. Smith (1925) obtained 57% clean carrots with several applications to the young plants of creosote (1%) absorbed in chalk (99%).

Anthomyiidae.

Brittain in a series of papers (1920, 1921, 1922, 1923, 1924) found a 1% mixture of creosote in clay (99%) applied dry at 700 lb./ac. (8 gm. creosote/sq. m.) gave a very effective control of the cabbage root maggot (*Hylemyia brassicae*, Bch.); usually less than 1% of the treated plants were infested. Smith (1925) reduced infestation by cabbage root maggot from 24 and 30% in the controls to 8% in plots treated with creosote (1%) absorbed in chalk (99%). The same mixture was even less effective in controlling the onion maggot (*H. antiqua*, Mg.) (1923 and 1925).

MYRIOPODA.

Horsfall and Eyer (1921) found creosote oil diluted to 1/100 and 1/25 had little effect in reducing the numbers of millepedes attacking seedlings in cold frames.

Riley (1929) applied a layer of sand saturated with creosote to the surface of the sub-soil, the top soil being afterwards replaced. This measure delayed the attacks of the glasshouse Symphylid (*Scutigerella immaculata*, Newp.) on lettuce for a few weeks, but later they came through in their usual numbers.

SUMMARY.

Critical experiments on creosote oils have been few in number, but they would certainly appear to be promising in the control of root maggots, and have occasionally given good results with other pests.

Anthracene Oils (Green Tar Oils).

These oils have a boiling range of about 270° C. and upwards. They comprise the range usually employed as winter washes for fruit trees. Anthracene itself is a solid hydrocarbon with the formula $C_{14}H_{10}$.

Experiments in Air (Pure Anthracene).

Tattersfield and Roberts (1920): non-toxic.
Fleming (1925): ineffective at 796 mg./l.

Experiments in Soil.

DIPTERA.

Psilidae.

K. M. Smith and Wadsworth (1921) found five applications of green tar oil (1%) and sand (99%) scattered between carrot rows resulted in 89% carrots unattacked by the carrot fly (*Psila rosae*, F.).

Anthomyiidae.

Stookey (1919) recommended one part of anthracene oil absorbed in 80 parts of soil scattered around cabbage plants to prevent attack by the root maggot (*Hylemyia brassicae*, Bch.). Brittain (1920, 1921, 1922, 1923) also obtained good results with anthracene oil (1%) absorbed in clay (99%) applied dry at 700 lb./ac. (8 gm. oil/sq. m.). The infestation was reduced to less than 2% in all experiments. K. M. Smith (1925), however, did not obtain such successful results with anthracene oil (5%) and chalk (95%) either for this insect or the onion fly (*H. antiqua*, Mg.), although previously (1923) he found a 1% anthracene-99% chalk mixture had resulted in a comparatively high yield of onions. K. M. Smith and Wadsworth (1921) found three applications of a 1% anthracene-99% sand mixture resulted in only 35% onions unattacked by the fly.

ISOPODA.

Speyer and Owen (1924) found anthracene in soil had little or no action on the cucumber-house woodlouse (*Armadillidium speyeri*, Jackson).

SUMMARY.

Pure anthracene appears to possess very little toxicity; anthracene oils absorbed in solids have been recommended for the control of root maggots but have not been invariably successful.

Miscellaneous Coal Tar Oils and Distillates.

This group covers references to unspecified substances, mostly proprietary preparations for fruit-tree winter washes, and, therefore, probably containing a high proportion of anthracene oil.

HEMIPTERA.

Aphidae.

Davidson (1917) used a 1½ to 6% tar distillate emulsion to control pear woolly aphis (*Eriosoma pyricola*, Bak. & Dav.) with good results, although 1 U.S. gal. was not enough to reach the deepest roots, and there was some scorching of the surface roots.

COLEOPTERA.

Scarabaeidae.

Davis and Luginbill (1921) found a proprietary preparation containing 12% phenols and 53% coal tar oils, diluted to 1/125 and applied at 1 U.S. gal./6 to 8 sq. ft. (4–5 gm./sq. m.), was a quite effective remedy for June beetle grubs (*Cotinis nitida*, L.). Preuss (1924) for a Melolonthid larva attacking cacao in West Africa, and Mallamaire (1934) for larvae of the Rutelid (*Adoretus umbrosus*, F.) recommended 1 to 2 l. per tree of a 3% solution of a tar distillate preparation. Cottier (1934) found that ¼ to 1 pint of a proprietary tar distillate emulsion applied in 3 gals.

water/sq. yd. (169 to 676 cc./sq. m.) gave high kills of the New Zealand grass grub (*Odontria zealandica*, White). The grass had to be well watered afterwards to prevent injury to the herbage.

Curculionidae.

Isaac (1923) found no reduction in numbers of cabbage galls made by the turnip gall weevil (*Ceuthorrhynchus pleurostigma*, Marsh.) on a plot treated with a tar product which consisted of a 1% neutral oil and a ground neutral residue and mixed with nine times its weight of chalk powder and applied at 5 lb./rod (90 gm./sq. m.).

Chrysomelidae.

Ripper (1934) obtained 100% kill of the flea beetle (*Chaetocnema aridula*, Gylh.) hibernating in the soil with 1–2 l./sq. m. (30–60 cc./sq. m.) of a 3% tar distillate emulsion.

Byturidae.

Korolkov (1913) found a 2% solution of carbolineum well watered into the soil gave good results in the control of larvae and pupae of the raspberry beetle (*Byturus tomentosus*, F.).

DIPTERA.

Tipulidae.

Senstius (1915) advised watering plant beds with a carbolineum diluted to 1/250 at 100 to 200 cc. carbolineum/sq. m., three or four months before planting, to control Tipulid larvae. If the beds were already planted the strength should be 1/500.

Mycetophilidae.

Speyer *et al.* (1939) found drenching the soil with a tar acid emulsion was effective in controlling larvae of *Plastosciara perniciosa*, Edw., and *Pnyxia scabiei*, Hopk., attacking young cucumber plants. On cucumber beds, however, the preparation was not successful even with four applications at 1/2,000 and four at 1/800.

Anthomyiidae.

Cabbage Root Maggot (*Hylemyia brassicae*, Bch.).

Brittain (1923) found various coal-tar products gave good protection (less than 1% plants attacked) against this pest in preliminary tests. Krasnyuk (1931) found three applications of 0·4 or 0·2% solution of a proprietary tar distillate at 120 cc. per plant resulted in only 1·3 and 3·3% of the plants being injured by the maggots. Gasow (1935) tested the toxicity of various distillates to eggs at 0·1 to 0·4% in laboratory experiments with satisfactory results. Edwards (1935) made applications at 10-day intervals of a 1/240 emulsion of a tar distillate at one pint per plant and obtained a 31% increase of unattacked plants over the controls, in which 71% of the plants were attacked.

Trypetidae.

Wiesmann (1934) obtained excellent results in the control of larvae and pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) with 5 l./sq. m. of an 8% emulsion for pupae, or 2% for larvae (100 and 400 gm./sq. m.). Thiem (1934, 1935, 1939) described tests made with carbolineums and tar distillates to control larvae and pupae of this insect at concentrations of 5 to 15%.

HYMENOPTERA.

Formicidae.

Walker and Anderson (1937) found a 1·5% solution of a tar acid oil gave good control of the pavement ant (*Tetramorium caespitum*, L.) attacking egg-plants, but injured the plants.

MISCELLANEOUS.

Molz (1911) reported favourably on the use of carbolineums at strengths of about 8% for the control of superficial soil insects.

Paradichlorbenzene ($C_6H_4Cl_2$).

P.-dichlorbenzene (often abbreviated to P.D.C.B. or P.D.B.) is one of the few substances which, for insecticidal purposes, has been almost exclusively used for soil treatment, although it is also employed as a control for clothes moths.

Effect on Plants.

Most authors stress the necessity for care in its application, and recommend an interval of some weeks between treatment and planting; Mungomery (1926) stated that sugar-cane was more susceptible to injury during periods of drought.

Application.

Paradichlorbenzene is almost invariably applied in small quantities (10–30 gm.) in holes made in the ground at regular intervals. Various forms of apparatus have been devised to facilitate this and to regulate the dose (Kostenko 1928, Makhnovskiĭ 1928). More recently it has been applied as a strong solution in various solvents, and in this form and pure it has been widely used in the U.S.A. in the control of the peach-tree borer. These solutions are sometimes emulsified with water before application.

Little or no work has been carried out on its distribution and determination in the soil. It does not appear to be effective in heavy soils (Burns 1929, and others), and at low temperatures it does not volatilise sufficiently rapidly to be toxic. This may account for its lack of success in this country. It is also not effective while the soil is wet, but acts again when the soil dries out (Jarvis 1924 *b*).

Experiments in Air.

Fleming (1925): minimum lethal dose in air 22 mg./l.; in water 322 mg./l.

Thalenhorst (1937) found 187 mg./l. to be the minimum lethal dose in air to kill third-instar grubs of *Melolontha hippocastani*, F., for a 24-hour exposure. He also found that a dose of 5 gm. gave 83% kill of grubs buried in cages in the soil 25 cm. deep, 14–25 cm. from the point of injection.

Experiments in Soil.

ORTHOPTERA.

Gryllidae.

Conte (1928) recommended paradichlorbenzene for the control of the mole-cricket, *Gryllotalpa gryllotalpa*, L., applied in furrows 5 cm. deep and 80–100 cm. apart at the rate of 150–200 gm./linear metre.

DERMAPTERA.

Forficulidae.

Steinweden (1934) found that 1 oz. (28 gm.)/ball had no effect in 48 hours on the earwig, *Forficula auricularia*, L., in balled nursery stock.

ISOPTERA.

Jepson (1926) found 1/24–1/8 oz. (1-4 gm.) had no effect on termites (*Calotermes* sp.) building nests under tea bushes. Hargreaves (1929), however, obtained good results in the treatment of citrus stock attacked by termites with paradichlorbenzene at ¼ oz. (7 gm.) per plant placed in a circle 3 ins. (7·5 cm.) radius and 2 ins. (5 cm.) deep.

THYSANOPTERA.

Richardson and Nelson (1933) applied paradichlorbenzene to the soil 1–1½ ins. (2·5–3·8 cm.) above gladiolus corms at the rate of 1 oz. (28 gm.) per 50 corms, but it was ineffective in controlling the gladiolus thrips (*Taeniothrips gladioli*, Mlt. & Stnw.) and also retarded the growth of the plants.

HEMIPTERA.

Coccidae.

Hargreaves (1924 *b*) stated that paradichlorbenzene killed the mealybugs (probably *Pseudococcus kenyae*, Le Pelley) attacking coffee, and also penetrated the rubbery substance they secrete about the roots. In 1927 he stated that 50% of coffee trees previously treated with 2½ oz. (70 gm.) were free from the insect. For larger trees it was necessary to bare the roots. Similar results were obtained by Hancock (1926). In an anonymous publication (Uganda Plant Pest Board, 1925) 1½–4 oz. (42–112 gm.) was recommended for the control of mealybugs attacking coffee. The lower rates were to be used on three-year-old trees.

Harris (1934) controlled a root-feeding Coccid on peppermint with paradichlorbenzene at 4 oz./sq. yd. (136 gm./sq. m.). Hosni and Shafik (1935) obtained 100% kill of the pineapple mealybug (*Pseudococcus brevipes*, Ckll.) on the roots of *Phoenix* sp. at 2–10 gm. per plant.

Aphidae.

Apple and Pear Root Aphids.

Howard (1918) reported that paradichlorbenzene gave promising results in the treatment of nursery stock infested with woolly apple aphis (*Eriosoma lanigerum*, Hsm.); 95% kills were obtained with ¾–1 oz. (21–28 gm. per tree) (1919). Its value was confirmed by Pettit (1925), and for older trees (Anon., Long Ashton, 1926) and by Marcovitch (1934), who found that ⅛ oz. (3½ gm.) destroyed the Aphids but was apt to injure the trees. French and Levick (1925) found a somewhat higher dose of 2½ oz. (70 gm.) per tree scattered on the surface, and worked in to a depth of 6 in. around the tree, necessary to give a complete kill of the pear woolly aphis (*Eriosoma pyricola* Bak. & Dav.). Essig (1922) successfully controlled the pear root aphis (*E. lanuginosum*, Htg.) on four-year-old pear trees with P.D.C.B.

Anuraphis persicae-niger, Smith (Black Peach Aphis).

Cory (1923 *b*) found that ½ oz. (14 gm.) per three-year-old tree, applied in a shallow depression and covered with earth, freed heavily infested peach trees within a year. Cutright (1925 and 1927) stated that ¼–⅓ oz. (7–9 gm.) was effective and was the largest amount tolerated by the trees, although Chandler (1940 *b*) also found ½ oz. (14 gm.) satisfactory as a control measure.

Grandori (1930 *b*) recommended two applications, one in November–December and the other in March–April, of 20 gm. paradichlorbenzene/linear metre, 15–20 cm. deep, to control the vine phylloxera (*Phylloxera vastatrix*, Planch.). At this rate the vines were uninjured.

LEPIDOPTERA.

Aegeriidae.

Aegeria exitiosa, Say (Peach Tree Borer).

Howard (1918 and 1919) mentioned the possibilities of paradichlorbenzene in the control of this insect, the larvae of which bore holes and galleries in the roots

and bases of the trunks of peach trees. Blakeslee (1919) published the first detailed account of its use, and his recommendations have formed the basis of all paradichlorbenzene treatments of the borer ever since. The method consists in placing a layer of crystals in a circle around the base of the tree either below ground level or, if at ground level, then mounded over with about 2 ins. (5 cm.) of soil. If the material is placed a few inches from the trunk little damage is caused to older trees. The amount suggested is ¾–1 oz. (21–28 gm.) per tree applied in the early autumn. This gives 100% kill within 14 days. The more recent modifications have largely been attempts to make the treatment suitable for younger trees and also to make it more certain in its action. Blakeslee's results were confirmed by Peterson (1921 *b* and 1923 *b*) in New Jersey; by Snapp and Alden (1923) in Georgia; by Haseman and Sullivan (1922) in Missouri; by Thompson (1927) in Oregon, and many others. Peterson (1923 *a*) obtained kills of 82–95% with ½ oz. (14 gm.) doses. Craighead (1923) recorded 90–99% kills at the same rates within 14 days, and Herrick (1923) kills of 94–100% with doses of ¾–1¼ oz. per tree.

Further recommendations in the amount for younger trees, the best time for treatment, and the necessity or otherwise of removing débris before treatment and the soil mound after treatment, were made by Snapp (1924) and Chandler (1924). The soil temperature of the mound is an important factor. Essig (1926) found the best results were obtained at 75–85° F., although according to Chandler (1939) the optimum temperature was 55–60° F., and above this too rapid volatilisation occurred. Most authors found the treatment was ineffective in the winter and was most successful in the autumn and to a lesser extent in the late spring. A full account of recent practices and recommendations is given by Chandler (1939).

Other Root Borers.

Peterson (1923*b*) found the same treatment successful for dealing with borers in plums and cherries but not for the round-headed borer of the apple (*Saperda candida*, F.) or the blackberry crown borer (*Pennisetia marginata*, Harr.). Guyton and Stear (1924) confirmed Peterson's view that the treatment injured apple trees.

Lathrop and Trask (1924) used this method in Oregon to control the prune root borer (*Aegeria opalescens*, Edw.), and Thompson (1926) found ½ oz. (14 gm.) successfully controlled this insect on cherries.

Noctuidae.

Hawley (1918) obtained satisfactory results (82–95% kills) of the hop borer (*Hydroecia immanis*, Gn.) with the application of a few crystals per hill. Esterberg (1932) successfully controlled an attack of the potato stem borer (*Hydroecia micacea*, Esp.) on onions by the application of 0·5 gm. per plant.

Tortricidae.

Chandler (1930) stated that paradichlorbenzene had not given consistently successful results in the control of larvae of the Oriental peach moth (*Cydia molesta*, Busck) overwintering at the base of the trunk of peach trees.

COLEOPTERA.

Scarabaeidae.

Howard (1922) stated that 300 lb. of paradichlorbenzene/ac. (34 gm./sq. m.) drilled in 1 in. (2·5 cm.) deep and 4 ins. (10 cm.) apart killed 75 % of the larvae of *Popillia japonica*, Newm.

Jarvis and his co-workers have published a long series of papers dealing with the control of the sugar-cane grub (*Dermolepida albohirtum*, Waterh.) in Queensland. Paradichlorbenzene has been extensively used for this purpose, and the history of its introduction and general recommendations for its use are given by Jarvis (1928 and 1929). The substance is used in amounts of ¼ oz. (7 gm.), or for some purposes ⅛ oz. (3·5 gm.), 4½–5 ins. (12 cm.) deep and 12–18 ins. (30–45 cm.) apart.

It is usually applied with a machine (Jarvis 1924 *a*) on both sides of the cane rows 6 ins. (15 cm.) from the stools. The rate is equivalent to about 1 cwt./ac. (13 gm./sq. m.).

Jarvis and Burns (1926) recorded 48 and 49% kills of the cane grub with this method, but judging from the frequency with which it is recommended it would appear to be usually more successful than this. Jarvis (1925 *b*) and Mungomery (1928 and 1929) have stressed the lengthy period over which P.D.C.B. is active, especially compared with carbon disulphide. According to the latter author, paradichlorbenzene should not be used in winter when the soil temperature is below 60° F. (16° C.), as the rate of vaporisation is then too slow. It is not effective in wet soils. Mungomery (1932) also recorded considerably reduced yields of sugar-cane on land treated with P.D.C.B.

Lopez (1931 *a*) found that for this reason paradichlorbenzene was not successful in the clay soils of the Philippines when used in the way suggested by Jarvis to control various species of sugar-cane grubs, as the most convenient time to apply it coincided with the start of the rainy season. Box (1925), however, obtained up to 85% kills of white grubs (*Lachnosterna* sp.) attacking sugar-cane in Porto Rico by scattering 1 oz. (28 gm.) per stool over the soil for a radius of 9 ins. (22·5 cm.) and following the application with watering.

Wolcott (1924) in Porto Rico found in laboratory experiments that 0·3 oz./cu. ft. (300 gm./cu. m.) was necessary to obtain complete kills of white grubs. This corresponded to the high rate of 800 lb./ac. (90 gm./sq. m.) in the field. Barrow (1924) for these grubs in Porto Rico and Wolters (1934) for grubs of *Anomala orientalis*, Waterh., in Hawaii both found P.D.C.B. ineffective at 200 and 400 lb./ac. (23 and 45 gm./sq. m.). The latter author used Jarvis's method of application.

Russian Work on various Scarabaeid Larvae, mainly *Melolontha hippocastani*, F., and *Polyphylla fullo*, L.

Golovyanko has published several papers (1927–1935) on the use of P.D.C.B. in the control of these grubs attacking vines and nursery stock of forest trees. In a general summary of the method (1935), he recommends the application of ¾ oz. (20 gm.) in holes 8 ins. (20 cm.) deep and 14 ins. (35 cm.) apart each way, the holes being covered in after the introduction of the fumigant. This corresponds to a rate of 364 lb./ac. (40 gm./sq. m.) and is suitable for sandy soils, but for heavy or compact soils more fumigant is required. The method was more effective if the crystals were spread evenly over the area of a square hole (2·5–2·75 sq. dec.) than if placed in a heap (1930, 1933). A mechanical means of introduction was devised (1930, 1935). Kills of 90–100% were frequently obtained using 7 gm./hole, with the holes 14–28 ins. (35–70 cm.) apart and 4–8 ins. (10–20 cm.) deep (1933).

Similar results have been obtained by Dekhtiarev (1929) with 100% kills at 240–300 lb./ac. (27–34 gm./sq. m.); by Zhirkov (1931) with 75, 90 and 100% kills at 20, 40 and 60 gm./sq. m. respectively; by Sokanovskiĭ (1932) with 100% kills at about 40 gm./sq. m.; and by Krasnyanskiĭ (1937) with 75% kills, also at about 40 gm./sq. m. Rekk (1930) reported high kills of Scarabaeid larvae attacking fruit trees treated with P.D.C.B. applied in rings around the trunk.

Chigarev (1930) pointed out that higher kills were obtained when the P.D.C.B. was introduced at lower depths than the 2½–5 ins. (6–12·5 cm.) then in common use. He (1932) also showed that higher kills (100%) for the same rate (40 gm./sq. m.) were obtained in open glades where the soil temperature was 9° C. higher than in the shady areas (81·8% kill).

Other Scarabaeid Larvae.

Strawinski (1928) obtained a complete kill of the larvae of *Amphimallus solstitialis*, L., with 4 gm. doses applied in holes 2–5 cm. deep and 25 cm. apart (36 gm./sq. m.). Grandori (1930 *a*), for the control of the cockchafer, *Melolontha vulgaris*, L., recommended strewing P.D.C.B. crystals in furrows 20–25 cm. deep and 1 m.

apart at 20 gm./linear m. The furrows should be filled in with earth and stamped down; the application should preferably be made in November or December. Applied under laboratory conditions, 10 gm./sq. m. gave a complete kill of grubs in a box.

Goidanich (1931) found P.D.C.B. gave effective control of the Dynastid, *Pentodon punctatus*, Villers, attacking young trees if applied 10–15 cm. deep at 12–20 gm. per plant in four holes 15–20 cm. from the tree. Cottier (1932) found P.D.C.B. at 3–4 oz./sq. yd. (102–136 gm./sq. m.) worked in to a depth of about 3 ins. (7·5 cm.) effective but expensive for the control of the New Zealand grass grub (*Odontria zealandica*, White). Franklin (1941) obtained a complete kill of larvae of *Amphicoma vulpina*, Hentz, on cranberry bogs by applying P.D.C.B. at 1200 lb./ac. (134 gm./sq. m.) and covering the crystals with a layer of sand about an inch thick. The method was very expensive.

Elateridae.

Hawkins (1928) found that P.D.C.B. at 100–200 lb./ac. (11–22 gm./sq. m.) apparently had no effect on the numbers of wireworms (mainly *Agriotes mancus*, Say) in treated plots in Maine; McDougall (1934) obtained negative results in the control of *Lacon variabilis*, Cand., attacking sugar-cane in Queensland with P.D.C.B. incorporated in the soil close to the sets at planting time at 680 lb./ac. (76 gm./sq. m.). Speyer *et al.* (1940) found P.D.C.B. applied to dibbled holes before tomatos were planted proved harmful to the plant at concentrations necessary to prevent wireworm attack.

Buprestidae.

Libes (1924) reported that he had used P.D.C.B. in the control of the black flat-headed borer (*Capnodis tenebrionis*, L.) on cherry trees at the rate of 24 gm. per 3–4-year-old tree applied as for peach borers in America. The older larvae were not killed by this amount, but there appeared to be less damage in the treated trees. Rekk (1932) also used P.D.C.B. for the same purpose, and at 32–64 gm. per tree kills up to 95% were obtained. The fumigant was applied in circular furrows 8–10 cm. deep and 10–13 cm. away from the tree and then covered with soil.

Curculionidae.

Isaac (1923) obtained negative results with P.D.C.B. applied to spring cabbages to control the turnip gall weevil (*Ceuthorrhynchus pleurostigma*, Marsh.). The crystals were diluted with nine times their weight of chalk powder and the mixtures applied at 5 lb./rod (9 gm./sq. m.). Barrow (1924) also found P.D.C.B. at 200 and 400 lb./ac. (22 and 45 gm./sq. m.) apparently ineffective in the control of the root borer, *Diaprepes spengleri*, L., attacking sugar-cane in Porto Rico. French and Hammond (1926) were unable to destroy larvae of the apple root borer (*Leptops hopei*, Fhs.) in Victoria with P.D.C.B. at ¾–3 oz. (21–84 gm.) per tree. Lovell (1932) was also unsuccessful in fumigating larvae and pupae of the vegetable weevil (*Listroderes obliquus*, Gylh.) with applications of 1 oz./4 ft. row (23 gm./m.) of carrots. F. F. Smith (1932) was, however, able to kill all larvae of the vine weevil (*Otiorrhynchus sulcatus*, F.) with 0·25 gm. of finely powdered P.D.C.B. per four-inch flower-pot of soil. Cyclamens tolerated up to 0·75 gm. per pot. Krasnyanskiĭ (1937) obtained 72–79% kill of grubs of *Otiorrhynchus turca*, Boh., with P.D.C.B. at 1 oz./sq. yd. (34 mg./sq. m.).

Chrysomelidae.

Weigel and Doucette (1922) found P.D.C.B. at 2–8 gm. per plant promising for the control of the strawberry root worm (*Paria canella*, F.) on roses, but the plants were injured by the treatment. Jarvis (1927 *a*) found that P.D.C.B. gave a satisfactory control of *Rhyparida morosa*, Jac., attacking the roots of young maize plants.

Cerambycidae.

Chamberlin (1925) found that P.D.C.B. at ½–1 oz. (14–28 gm.) per plant had little effect on the gooseberry root borer (*Xylocrius agassizii*, Lec.). On the other hand, it has been found (Oregon 1928) that 1 oz. (28 gm.) per plant gave promising results for the control of this insect. Crawford and Eyer (1928) obtained about 50% kill, after three months, of larvae of *Prionus californicus*, Motsch., with 2–4 oz. (56–112 gm.) placed in early June around each of the infested trees 5–6 ins. (12½–15 cm.) from the trunk.

DIPTERA.

Cecidomyiidae.

Olombel (1931) stated that cauliflowers grown on soil treated with 1500 kg. P.D.C.B./ha. (150 gm./sq. m.) were less severely attacked by the midge, *Contarinia torquens*, de Meij., than those grown on untreated soil. Mühlow and Sjöberg (1937) found no reduction in the infestation by wheat gall midges (*C. tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) on wheat plots sprinkled with P.D.C.B. in sand.

Mycetophilidae and Chironomidae.

R. W. Thompson (1929) obtained a complete kill of larvae of *Sciara caesar*, Johannsen, and *Smittia byssina*, Schr., injuring the roots of various plants in a glasshouse, with P.D.C.B. scattered over the soil at 2 lb./100 sq. ft. (100 gm./sq. m.) and then covered over with 2 ins. (5 cm.) of soil. Only 20% of the larvae were killed if the layer was left uncovered. This operation should be carried out at least four weeks before planting. Fulton (1933) found P.D.C.B. caused no reduction in the numbers of midges emerging from seed-beds where the larvae had been causing damage.

Psilidae.

K. M. Smith and Wadsworth (1921) found five applications of P.D.C.B. to carrots at ½ oz. /sq. yd. (17 gm./sq. m.) were ineffective in preventing infestation by the carrot fly (*Psila rosae*, F.).

Anthomyiidae.

Brittain (1920) recorded 3 and 6% cabbage plants destroyed by the cabbage maggot (*Hylemyia brassicae*, Bch.) on plots treated with 10% P.D.C.B. and 90% Scotch soot applied dry at 700 lb./ac. (78 gm./sq. m.). The percentage of plants destroyed in the control plots varied from 17–44. The following year (1921) he recorded 16–22% treated plants destroyed compared with 56–65% in the controls. Goffart (1933) obtained unsatisfactory and inconclusive results with P.D.C.B. at 2 gm./sq. m. for the control of cabbage root maggot.

Trypetidae.

Samoggia (1932) found P.D.C.B. gave an effective control of cherry fruit-fly (*Rhagoletis cerasi*, L.) when the larvae descend to the ground to pupate. He recommended 35–40 gm. applied in 8–12 furrows 3–4 cm. deep radiating from the foot of the plant to just outside the limit of the leaf system. Alternatively 30 gm. could be applied in four or five concentric circles over the same area. He found the pupae were much more resistant than the larvae. Wiesmann (1934) advised P.D.C.B. at 20–40 gm./sq. m. for the control of the pupae and obtained 100% kill of them at this rate. He obtained 90–100% kill of the larvae when these were introduced into soil treated with 30–40 gm./sq. m. up to three and five days after treatment. Thiem (1934) found P.D.C.B. gave good control of the pupae in pot experiments with 5–10 gm. per pot 15 cm. wide (250–500 gm./sq. m.). P.D.C.B. applied in the field in little heaps at about this rate resulted in fewer flies (16–28%) emerging than any other substance tested.

HYMENOPTERA.

Formicidae.

Hutson (1936) recommended P.D.C.B. at 1 oz./sq. yd. (34 gm./sq. m.) to kill the ant, *Dorylus orientalis*, Westw., which injures underground parts of ornamental plants and vegetables. It should be applied when the soil is dry, sprinkled along shallow furrows between the rows of plants at ¼ oz./yd. of furrow (8 gm./m.) and the soil afterwards replaced.

MYRIOPODA.

Scutigerella immaculata, Newp. (Glasshouse Symphylid).

Wymore (1931), after obtaining promising results in the control of this pest in the laboratory, found P.D.C.B. unsatisfactory in the field at 300 lb./ac. (34 gm./sq. m.) when applied to asparagus beds in furrows 6–7 ins. (15–17·5 cm.) deep. Negative results were also obtained (Oregon 1928) at ½ lb./1000 sq. ft. (2·5 gm./sq. m.), and by Brunetau (1935) at 400 kg./ha. (40 gm./sq. m.) applied in ridges 40 cm. apart and 15 cm. deep. Filinger (1928, 1931 *b*) and Riley (1929) broadcast the substance on the subsoil after the topsoil had been removed. After this had been replaced, the P.D.C.B. acted as a barrier to the Symphylids in the subsoil. Filinger found this effective at 1 and 1½ lb./100 sq. ft. (50–75 gm./sq. m.), but Riley reported only slight delay in the incidence of the attack at 10 lb./100 sq. ft. (500 gm./sq. m.). Michelbacher (1932), however, obtained 100% kill on small plots with 600 and 900 lb./ac. (67 and 101 gm./sq. m.) and 80% kill at 300 lb./ac. (34 gm./sq. m.) when the P.D.C.B. was applied broadcast in furrows 10 ins. (25 cm.) wide, 18 ins. (45 cm.) apart, and 6 ins. (15 cm.) deep.

SUMMARY.

Paradichlorbenzene has been used successfully against several root pests of trees when applied about 15–30 gm. per tree. Unless used carefully, serious injury to the tree is liable to result. In Russia, especially, it has been extensively used to control various Lamellicorn larvae, and for this purpose it is usually applied in holes 20–40 cm. apart and about 40 gm./sq. m. It has also been applied in furrows up to 500 gm./sq. m. for the control of various soil pests, but often without success. It is active for a very long time.

Paradichlorbenzene applied in various Solvents.

HEMIPTERA.

Aphidae.

Printz (1935) stated that a solution of P.D.C.B. in carbon disulphide (0·3 oz. and 0·9 oz. respectively/sq. yd., or 10 gm. in 30 gm./sq .m.) gave satisfactory kills of *Phylloxera*. Later (1940) he recorded complete mortality to a depth of 24–40 ins. (60–100 cm.) with this solution at 4·2 oz./sq. yd. (145 gm./sq. m.) applied in holes 6–7 ins. (15–17·5 cm.) deep and 14 ins. (35 cm.) apart. The P.D.C.B. was effective in the surface layer, whereas the carbon disulphide was more effective below 4 ins. (10 cm.).

LEPIDOPTERA.

Aegeriidae.

Aegeria exitiosa, Say (Peach Tree Borer).

Siegler (1927) obtained promising results with 1 oz. of P.D.C.B. dissolved in 50 cc. gasoline (petrol) per tree instead of applying it, as usual, in crystals. Siegler and Brown (1929) reported that this treatment was effective without the previous preparation of the soil or the mounding up around the tree necessary when the crystals were applied in the usual way. Snapp and Swingle (1929), however, tried this method unsuccessfully, but Snapp (1932) later reported on it favourably.

Cory (1928 *a*) dissolved P.D.C.B. in pine oil at 100 gm./100 cc. and then emulsified this solution with soap, diluting it to 1 in 9 and 1 in 4. Applications with these strengths injured apple trees but not peach trees, and in both cases high kills of worms were secured. Snapp and Thomson (1934 *a* and 1936) found that cotton-seed oil emulsions of P.D.C.B. were safer and quicker, though slightly less effective, than crystals alone, especially in the treatment of younger trees. The amounts used were $\frac{1}{8}$–$\frac{3}{4}$ oz. (4–21 gm.) of P.D.C.B. to $\frac{1}{4}$–1 U.S. pt. (120–474 cc.) of oil according to the age of the tree. Kills of 59–100% were obtained. In mineral oils and gasoline and kerosene, good control was obtained, but injury to nursery stock resulted.

Chandler (1936 and 1939) found proprietary miscible oils, soya-bean oil, cotton-seed oil, and mineral oils were satisfactory solvents. He used $\frac{1}{4}$–1 oz. P.D.C.B. in $\frac{1}{4}$ to $\frac{1}{2}$ U.S. pint of solvent per tree and, though they did not give increased kills, such mixtures could be applied to young trees without injury, and by using a spraying machine the work could be done more quickly. A device for delivering regulated amounts of liquid for this purpose was described by Snapp and Thomson (1934 *b*). Worthley and Steiner (1942), however, found that tree injury tended to be more severe with liquid applications than with crystals. They suggested that the amount of injury was correlated with soil and climatic conditions.

Other Borers.

Chandler (1936) found the lesser peach tree borer (*Aegeria pictipes*, G. & R.) more resistant than *A. exitiosa*, and found 2 oz. of P.D.C.B. in a miscible oil gave 83% kill. In an anonymous report (New York 1937) it is stated that 2 lb. P.D.C.B./1 U.S. gal. crude cotton-seed oil (240 gm./l.) painted on peach trees gave 75% kill of *A. pictipes*.

COLEOPTERA.

Scarabaeidae.

Printz (1932) found P.D.C.B. dissolved in carbon disulphide in the proportion of 1 : 2 and applied at 2·1–2·4 oz./sq. yd. (70–80 gm./sq. m.) in June killed all larvae of *Polyphylla olivieri*, Lap.

Jarvis (1930 *a*) used a solution of P.D.C.B. in carbon disulphide as a convenient method of application to control cane grubs (*Dermolepida albohirtum*, Waterh.). 80–85 lb. of each was used per acre (9·0–9·5 gm./sq. m.), the maximum amount applied to a large stool being 22 cc. in four injections. Mungomery (1931) injected a saturated solution of P.D.C.B. in carbon disulphide 4 ins. (10 cm.) deep in 4·8 cc. doses on both sides of sugar-cane stools and obtained 75% kill of cane grubs (*Pseudo-holophylla furfuracea*, Burm.). Bell (1934), for the control of another cane grub (*Dermolepida albohirtum*, Waterh.), found a mixture of equal parts of P.D.C.B. and carbon disulphide slightly more effective than either used alone. The following year (1935) he recommended two parts carbon disulphide to one part of P.D.C.B., and this combination gave the best control of all remedies tried.

Bennett (1940) obtained 75% mortality of chafer beetle larvae (*Phyllopertha horticola*, L.) in small artificially infested plots with a mixture of 1 lb. P.D.C.B. and 4 lb. naphthalene dissolved in 1 gal. benzene at a concentration equivalent to 4 cwt./ac. (50 gm. mixture/sq. m.).

Elateridae.

Pepper (1937) tested P.D.C.B. in carbon disulphide emulsion on various species of wireworms. The mixture was applied direct to cabbages, cauliflowers and collards; $\frac{1}{8}$ oz. carbon disulphide containing 1 gm. P.D.C.B./ U.S. pint/plant gave 84 and 85% kills. Dissolved in cotton-seed oil only 55% kill was obtained. No injury was caused to the plants with these amounts. Miles and Cohen (1939) found an emulsion containing 10% carbon disulphide and 0·7% P.D.C.B. was an effective soil fumigant for wireworms (*Agriotes* sp.).

Curculionidae.

Marlatt (1931) recommended a 4% emulsion of P.D.C.B. dissolved in a mineral oil sprayed on the soil for the control of plum curculio pupae (*Conotrachelus nenuphar*, Hbst.).

Chrysomelidae.

Feytaud (1932) found a solution of 25 gm. P.D.C.B. in 50 gm. benzene, emulsified with soap and water and applied at 1 l./sq. m., was useless to control Colorado beetles (*Leptinotarsa decemlineata*, Say) hibernating in the ground.

Cerambycidae.

In an anonymous publication (New Mexico 1935) it was stated that a solution of P.D.C.B. in petrol at 3¼ oz./U.S. pint/cu. ft. gave 100% kill of larvae of the root borer, *Prionus californicus*, Motsch., buried in artificial trenches.

DIPTERA.

Cecidomyiidae.

Mühlow and Sjöberg (1937), using a solution of P.D.C.B. in kerosene at 1 gal./100 sq. yd., obtained a marked reduction of infestation by wheat gall-midges (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.). This caused only slight injury to the crop, though at 2 gals./100 sq. yd. the injury was severe.

Trypetidae.

Wiesmann (1934) found a P.D.C.B. emulsion did not remain toxic in the soil to larvae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) very long after treatment.

Hammer (1934) found an emulsion of a saturated solution of P.D.C.B. in kerosene gave a high kill of apple maggot pupae (*Rhagoletis pomonella*, Walsh), though not much higher than kerosene alone.

Dichlorethyl Ether ($CH_2Cl.CHCl.O.CH_2CH_3$ ($\alpha\beta$)).
($CH_2Cl.CH_2O.CH_2.CH_2Cl$ ($\beta\beta'$)).

Liquid. S.G. 1·22 at 20° C.

Attention was first drawn to this substance by Lehman (1933), who observed a marked difference in the relative toxicity of the $\alpha\beta$ and $\beta\beta'$ forms to the wireworm, *Pheletes californicus*, Mannh. Several American workers have shown it to be highly toxic to wireworms, and it has since been tested extensively for other soil insects. Its principal disadvantage is its expense.

Experiments in Air.

Lehman (1933) recorded the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh., for a five-hour exposure at 25° C., as 3·41 mg./l. for the $\alpha\beta$ form and 0·90 mg./l. for the $\beta\beta'$ form; these were respectively 9·2 and 35 times as toxic as carbon disulphide under the same conditions.

Experiments in Soil.

(These all refer to the $\beta\beta'$ form.)

THYSANOPTERA.

Jones (1940 *a*) treated soil with 10 cc. dissolved in 1 U.S. gal. water/sq. yd. (14 gm./sq. m.) (using 0·5 gm. of a miscible oil to improve the solution) for the control of pear thrips (*Taeniothrips inconsequens*, Uzel). No thrips emerged from the soil thus treated, but several thousand emerged from untreated soil.

HEMIPTERA.

Aphidae.

Underhill and Cox (1940) found dichlorethyl ether at a dilution of 1/800 gave satisfactory control of woolly apple aphis (*Eriosoma lanigerum*, Hsm.), when applied to the soil at 1 U.S. gal./sq. ft. (62 gm./sq. m.) without injuring apple roots. Higher rates scorched the roots and in some cases killed the trees.

LEPIDOPTERA.

Aegeriidae.

Chandler (1939) found a solution of 30 cc./U.S. gal. applied at ¾ and 1 U.S. pint per tree (3 and 5 gm./tree) resulted in 60 and 19% kill of peach tree borers (*Aegeria exitiosa*, Say), respectively. The inconsistency was probably due to the small numbers of borers per tree.

Crambidae.

Stone and Elmore (1937) obtained 65 and 100% kill of sod webworms in lawns with solutions of 5 and 10 cc. ether/U.S. gal./sq. yd. (7 and 14 gm./sq. m.). The pupae were unaffected. Bohart (1940) also obtained high kills of *Crambus* sp. in California using a similar rate (1/400 solution at 1 U.S. gal./sq. yd. or 13 gm./sq. m.), but Jewett (1939) in Kentucky only obtained 31 and 54% kills at this rate.

COLEOPTERA.

Scarabaeidae.

Bell (1935) found dichlorethyl ether to be inferior to carbon disulphide as an insecticide for the sugar-cane grub (*Dermolepida albohirtum*, Waterh.). Hartzell and Wilcoxon (1939) found a saturated solution (8·3 cc./l.) applied at 1 U.S. gal./sq. yd. (46 gm./sq. m.) with a power sprayer gave poor control of Japanese beetle larvae at the end of the summer before all the eggs were hatched, but applied at the end of September, 68 and 62% mortality was recorded with only slight injury to turf. Two applications at 4–5-day intervals resulted in 96 and 80% mortality but caused severe injury to the turf. The addition of a small quantity of a sulphated alcohol improved the kill. Ritcher and Jewett (1942) averaged 81% kill of grubs of *Phyllophaga hirticula*, Knoch, and 79% of *Cotinis nitida*, L., with solutions of 32 cc. dichlorethyl ether/U.S. gal. applied at 2 U.S. gal./sq. yd. (94 gm./sq. m.). Half that amount was quite ineffective; a few cc. of a sulphated alcohol assisted solution but did not enhance the toxicity. The treatment had little, if any, deleterious effect on blue grass, but was toxic to various weeds.

Elateridae.

Campbell and Stone (1937) obtained complete kills of wireworms, *Pheletes californicus*, Mannh., to a depth of 8 ins. (20 cm.) with a solution of 5 cc./U.S. gal. Only 30 and 33% kills were obtained at a depth of 12 ins. (30 cm.). 1 U.S. gal. of this strength per 15 ft. of row (5 gm./m.) applied to rows previously baited with beans gave 97% kill on a heavy loam, but inconsistent results on a sandy loam. Strong (1938) recorded kills of 67 and 100% with solutions of 6, 9 and 12 cc./U.S. gal. applied to various crops in California to control wireworms. Only the strongest solution caused injury to plants. Pepper (1940) applied emulsions direct to various plants. Doses of 5 cc. were tolerated by most vegetables tested, and kills of 98–100% of wireworms were obtained in the surrounding soil. Speyer (1940), however, reported injury to tomatos at concentrations of 1/250 and 1/1,000. Campbell (1942) investigated the repellent action of dichlorethyl ether to the wireworms, *Pheletes canus*, Lec., and *P. californicus*, Mannh. Mixed with an inert carrier and applied to the soil at planting time as a dust, it reduced wireworm attack on melon seeds but affected germination. When applied in dilute solution, it effectively protected seedlings and young plants for three weeks. Promising results were also obtained

with 10 fl. oz./U.S. gal. applied at 1 U.S. qt. per hill. Gough (1942) obtained 85 to 100% kill of *Agriotes* sp. in pot experiments with 0·25 to 1·0% emulsions applied at rates corresponding to 23–94 cc. ether/sq. yd. (33–146 gm./sq. m.).

Curculionidae.

Snapp (1939 *a*) in laboratory tests obtained complete mortality of larvae of the plum curculio (*Conotrachelus nenuphar*, Hbst.) with solutions of ⅓ fl. oz./U.S. gal./sq. yd. (14 gm./sq. m.). The same rate gave 67% kill of the pupae. In field tests under peach trees the same result was obtained, and 1 fl. oz./gal./sq. yd. (42 gm./sq. m.) killed all the pupae without any injurious effect on the tree. Schwardt and Lincoln (1940) only obtained a low kill of larvae of the alfalfa snout beetle (*Otiorrhynchus ligustici*, L.) with 15 cc. doses of dichlorethyl ether injected 15 ins. (38 cm.) apart (161 gm./sq. m.). A somewhat higher kill (53%) was recorded in an examination four weeks after treatment.

DIPTERA.

Mycetophilidae.

Speyer *et al.* (1940) found dichlorethyl ether solution highly toxic in preliminary trials to larvae of a Mycetophilid fly injuring cucumber roots.

The Addition of other Substances to Dichlorethyl Ether.

Methyl Bromide.

Lincoln *et al.* (1942) mixed equal quantities of the two substances and water containing an emulsifying agent to make a stock emulsion, with the object of improving the toxicity of methyl bromide, which had previously given unsuccessful results in the control of the alfalfa snout beetle (*Otiorrhynchus ligustici*, L.) in the surface layer of soil. 450 cc. of the stock emulsion applied in 5 U.S. gals. water/100 sq. ft. (20 gm./sq. m.) gave complete control at all levels, though they recommended a slightly higher rate (600 cc. stock) for general use. There was a noticeable stunting of the alfalfa.

SUMMARY.

Dichlorethyl ether is one of the few new substances which has given really satisfactory results as a soil insecticide. It has been used successfully to control a large variety of pests at rates ranging from 14–100 gm./sq. m. It would seem to be well worth while testing even more thoroughly, though its cost is rather high.

Lead Arsenate ($PbHAsO_4$).

Crystalline.

The use of lead arsenate sprays and dusts as stomach poisons, especially for fruit tree pests, has been developed extensively in recent years and a finely divided and standard product can now be obtained. Acid lead arsenate is the form most frequently used nowadays, and it is more toxic to *Popillia japonica*, Newm., larvae than basic lead arsenate (Leach 1926, Fleming and Baker 1936, Fleming 1942). It is assumed that unless specifically stated otherwise, acid lead arsenate is the one referred to by experimenters. Lead arsenate also appears to be the most effective as a soil insecticide of all the other arsenates tested (Leach 1926, Fleming and Baker 1936, Fleming 1942). According to Fleming (1936), it should contain at least 30% arsenious pentoxide and not more than 0·75% of water soluble arsenic expressed as metallic arsenic. The Ministry of Agriculture, however, requires a minimum As_2O_5 content of 31% and a maximum water soluble As_2O_5 content of 0·5% (1934). These requirements are usually satisfied by standard agricultural sprays. Its use in the soil is based on the supposition that soil insects will not be able to avoid taking up arsenic present in the soil when feeding on plant roots or remains. In the amounts applied, a considerable period is likely to elapse

before an insect consumes sufficient arsenic to kill it, but the results in certain cases appear to justify the use of this substance.

It has, however, proved particularly useful for the larvae of numerous species of Scarabaeid beetles, especially on grassland, and can be incorporated into lawns which are being laid down, where it effectively prevents attack for about five years. Hallock (1935) has suggested that its success is partially due to the fact that as it remains effective in the top layer of soil, larvae of the Oriental beetle (*Anomala orientalis*, Waterh.), which were too deep to be affected at the time of application, and which would not have been affected by other types of soil fumigants, are killed when they return to the surface layer to feed.

Hamilton (1931 *a*) has described the penetration of lead arsenate into the sod and gives tables showing the amounts recovered at different depths down to 11½ ins. He also (1931 *b*) found little difference between the toxicity of two colloidal types and the ordinary powder to the grubs of the Asiatic garden beetle (*Autoserica castanea*, Arr.).

Estimation in and Reaction with Soil.

Koblitsky (1939) has described a method for the determination of arsenic in small quantities in the soil.

Fleming *et al.* (1936) showed that the variation of toxicity in different types of soil appeared to be correlated with the water soluble constituents of the soil. A greater concentration of soluble phosphate and calcium in the soil rendered the arsenate more effective, and a greater concentration of soluble magnesium rendered it less effective. Lime (Fleming 1936) reduced the effectiveness of the treatment. Fleming (1942) also found that regrinding the material to a smaller particle size significantly increased its effectiveness. Ginsburg (1940) has discussed the effects that might result from the combination of lead arsenate with certain salts which are likely to be present in soil.

Effect on Plants.

Most authors recommend that a period of months should elapse between application and planting or sowing. Fleming (1927) attempted unsuccessfully to reduce its toxicity to certain plants by coating the particles with paraffin and various oils and fats.

Experiments in Soil.

ISOPTERA.

Headlee and Jobbins (1939) found that termites (*Reticulitermes flavipes*, Kollar) would not enter areas of soil intimately mixed with lead arsenate at the rate of 0·05–0·40 lb./cu. ft. This is equivalent to 726–5,808 lb./ac. at 4 ins. deep (80–650 gm./sq. m.).

LEPIDOPTERA.

Crambidae.

Stirrett and Arnott (1932) treated golf greens damaged by these insects with lead arsenate at 2½–3 lb. per 1,000 sq. ft. (12–15 gm./sq. m.) in June. The treated greens were in good condition in July, whereas the controls were badly damaged. A second treatment of 4lb./1,000 sq.ft. (20 gm./sq. m.) controlled an outbreak caused by the second brood in September. The treated greens, however, received large quantities of water, and this may have been partly responsible for the difference.

North and Thompson (1933) used a spray at 2 lb./20 U.S. gals./1,000 sq .ft. (10 gm./sq. m.). This reduced the damage by the web-worms from 86 units in the controls to 24 in the treated plots. Jewett (1939) treated 20 sq. ft. with ½ U.S. gal. of a spray at about the same strength and obtained a mortality of about 90% of caged larvae in three successive seasons. Bohart (1940) also obtained kills approaching 100% of *Crambus bonifatellus*, Hulst, and *C. sperryellus*, Klots, in California with a

spray of 5 lb./50 U.S. gals. per 1,000 sq. ft. (25 gm./sq. m.). Noble (1932), however, found a lead arsenate suspension of 2 lb./50 U.S. gals. (4·7 gm./l.) applied at 2 U.S. qt./sq. yd. (1 gm./sq. m.) was ineffective, as was also an undiluted dust at 12 oz./1,000 sq. ft. (4 gm./sq. m.).

Noctuidae.

Hawley (1918) found a mixture of lead arsenate (1 part) and sulphur (4 parts) at the rate of one handful per hill was ineffective in controlling the hop borer (*Hydroecia immanis*, Gn.). A lead arsenate spray (5 lb./50 U.S. gals.) applied at 1 U.S. pint per hill was also ineffective.

COLEOPTERA.

Scarabaeidae.

Leefmans (1915) appears to have been one of the earliest users of lead arsenate for soil insects. He used a ½% suspension watered on the soil to control the cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.) with inconclusive results.

Leach (1926) in small pot experiments, and later on plots, found that all Japanese beetle larvae (*Popillia japonica*, Newm.) were killed in soil treated with 1,500 lb./ac. (168 gm./sq. m.). This dose was tolerated by some plants. The same rate was recommended by Leach and Lipp (1927) for grub-proofing soil against this insect in the preparation of lawns. They claimed the treatment was effective for five years. In certain areas of America this has become a routine treatment to prevent infestation by the Japanese beetle and similar species (L. B. Smith 1929). Fleming and Baker (1930) recommended a similar rate (35 lb./1,000 sq. ft. or 175 gm./sq. m.) to destroy the larvae in potting soil and plant beds and stated that it was not effective for some time after treatment and was best applied when the eggs were hatching. This measure is recognised by the U.S. quarantine authorities, who specify that for plant beds the arsenate must be thoroughly mixed with the top 3 inches (7·5 cm.) of soil and applied before 1st August and not planted till 1st October (U.S. Department of Agriculture, 1939 *b*).

Metzger (1933) obtained a satisfactory control of Japanese beetle larvae in rose greenhouses by incorporating lead arsenate at the rate of 1,000–3,000 lb./acre (112–336 gm./sq. m.) with the top 6 ins. (15 cm.) of soil.

Hallock (1930, 1932) found lead arsenate at about 35 lb./1,000 sq. ft. (175 gm./sq. m.) bulked with dry soil and broadcast on the surface, and afterwards thoroughly disced in, effectively prevented infestation of new lawns by the Asiatic garden beetle (*Autoserica castanea*, Arr.). To control infestations on old lawns, he (1932) recommended 15 lb. arsenate per 1,000 sq. ft. (75 gm./sq. m.). Strong (1931) and Fleming (1936) described the use of high-pressure power sprayers for applying the lead arsenate and recommended respectively 1 lb./U.S. gal. at 500 lb. lead arsenate/ac. (56 gm./sq. m.) and 1 lb./2 U.S. gals. at 10 lb./1,000 sq. ft. (50 gm./sq. m.) for the control of Japanese beetle. Afterwards the turf should be well washed down with water. For large areas where this method was impracticable, Fleming (1936) applied a mixture of lead arsenate and activated sludge or sand (in the ratio of 1 : 4) with a manure distributor.

Hartzel and Wilcoxon (1939) obtained a very small immediate kill of Japanese beetle larvae with a dry application of 10 lb./1,000 sq. ft. (50 gm./sq. m.), but there was a 72% reduction in grubs the following season. On the other hand Langford *et al.* (1939) found that standard lead arsenate applied at this rate in June resulted in an average of 1·26 larvae/sq. ft. in August and September compared with 12·6 in the control plots. A colloidal lead arsenate applied at 0·66 lb./1,000 sq. ft. (3 gm./sq. m.), according to the manufacturers' recommendations, had no effect.

For various species of white grubs (*Lachnosterna* sp.) in lawns, Filinger (1931 *a*) and Neiswander (1935, 1936, 1938) applied lead arsenate at 5 lb./1,000 sq. ft. (25 gm./sq. m.). Neiswander recorded a total reduction of 40·5% of grubs, including 66% first-year grubs (1935) and 77% of newly hatched grubs (1936). On the other hand, Hermans (1932) found this rate unsuccessful against May grubs (*Melolontha*

sp.). Hammond (1940) for the control of *Lachnosterna* sp. in Canada recommended 10 lb./1,000 sq. ft. (50 gm./sq. m.) thoroughly raked into the surface after the old sod had been ploughed in. For the control of the New Zealand grass grub (*Odontria zealandica*, White) in New Zealand, Cottier (1932) has recommended lead arsenate at 2 lb./100 sq. ft. (100 gm./sq. m.) and Dumbleton (1941) 1 lb./100 sq. ft. (50 gm./sq. m.). Johnson (1939) obtained excellent results in the control of the Dynastid, *Cyclocephala borealis*, Arr., on lawns with an application of 3 lb./100 sq. ft. (150 gm./sq. m.) in the autumn. Nichol (1935) estimated 55% mortality of the fig beetle (*Cotinis texana*, Casey) in Arizona with 1 lb. of lead arsenate lightly raked into the surface of an area 20 ft. square (12 gm./sq. m.). Sawa (1936) found that all larvae of *Anomala rufocuprea*, Motsch., were killed in soil containing 0·4% lead arsenate within four days. Older larvae were more resistant, but were all killed in 22 days in soil mixed with 0·8 %.

Kerr (1940) has described a method of preventing white grub (*Lachnosterna* sp.) attack on strawberries by applying $1\frac{1}{2}$ oz. (42 gm.) of a mixture of lead arsenate and sand (1/10–1/50) in a hole before setting out plants. Fleming (1942) adopted lead arsenate as a standard soil insecticide with which to compare the toxicity of other substances to *Popillia japonica*, Newm., larvae. At 1,000–2,000 lb./ac. (112–224 gm./sq. m.) very high kills were obtained, and its toxicity was maintained for about a year.

Elateridae.

Woodworth (1938) showed that wireworms were unable to take any but the very smallest particles into the gut, and that therefore they were unaffected by lead arsenate even when they ate corn-starch pellets containing it. They also survived immersion in a saturated arsenate solution for a week.

Curculionidae.

F. F. Smith (1927) stated that 0·5–16 oz. lead arsenate per bushel of soil apparently prevented the development of all grubs of *Otiorrhynchus sulcatus*, F., and had no detrimental effect on primulas and cyclamens. Later (1932) he recommended 1–2 oz. per bushel (8–16 gm./cu. m.). McDaniel (1932) recovered 275 beetles and pupae of the strawberry root weevil (*Otiorrhynchus ovatus*, F.) attacking conifer seedlings on plots treated with 5 lb. lead arsenate/1,000 sq. ft. (20 gm./sq. m.), compared with 503 beetles and pupae on the control plots.

Cerambycidae.

It was found (New Mexico 1935) that 1·7 U.S. gals./cu. ft. of a suspension of 3 lb./U.S. gals. was ineffective in the control of larvae of *Prionus californicus*, Motsch.

DIPTERA.

Tipulidae.

Dawson (1932) recorded an experiment in which the population of leatherjackets (*Tipula* sp.) in a golf green had apparently dropped from 330/sq. yd. in November to 13/sq. yd. in January after treatment with lead arsenate at 5 lb./1000 sq. ft. (25 gm./sq. m.). Dawson and Ferro (1936) recommended $\frac{1}{2}$–2 oz. of powdered lead arsenate/sq. yd. (17–68 gm./sq. m.) or 1–$1\frac{1}{2}$ pints of colloidal arsenate/25 sq. yd. (43–65 gm./sq. m.). This latter treatment gave 70–98% kill at various centres.

Bibionidae.

Edwards (1941) obtained 99·6–99% kill of larvae of the fever fly, *Dilophus febrilis*, L., in lawns with powdered lead arsenate distributed evenly at $1\frac{1}{2}$ oz./sq. yd. (50 gm./sq. m.), and watered into the soil.

MYRICPODA.

Michelbacher (1932) found lead arsenate broadcast over small plots at 300 lb./acre (34 gm./sq. m.) ineffective for the control of the glasshouse Symphylid, *Scutigerella immaculata*, Newp.

SUMMARY.

For the control of Crambid larvae, rates ranging from 10–25 gm./sq. m. have been used successfully. For the control of Scarabaeid larvae (Japanese beetle, Asiatic beetle, white grubs, etc.) about 170 gm./sq. m. is recommended for grub-proofing new lawns. This treatment is, however, expensive and is at best only a delaying measure (U.S. Dep. Agric. 1935). For the treatment of older lawns that have become infested, 50 gm./sq. m. was recommended and frequently gave high kills. Rates of 25–100 gm./sq. m. have been used in the control of various insects. Lead arsenate has rarely been used, and would not appear to be suitable, for the control of wireworms.

Naphthalene ($C_{10}H_8$).

Crystalline.

Although naphthalene is widely used as a soil fumigant and forms the basis of many proprietary preparations, comparatively few critical experiments have been performed to test it. As a by-product of the distillation of coal, it is easily obtained in large quantities, and it has the advantages of being easy to handle and non-toxic to human beings. Naphthalene is used in various forms according to the degree of refinement. Mixed residues of distillates containing a high proportion of phenol are often referred to as crude naphthalene or drained creosote salts and may be variously coloured. The purer forms, Grade 16 and whizzed naphthalene, can easily be crystallised out (Miles 1929).

Estimation.

Fleming and Baker (1934) have prepared a summary of the use of naphthalene as a soil insecticide especially for the Japanese beetle, and they give details of its estimation in the soil. They found the precipitation of naphthalene picrate in the presence of excess picric acid unreliable and slow, and recommended the method of Calcott *et al.* (1924). This depends on the fact that sulphonated naphthalene is oxidised practically quantitatively to sulphothalic acid by means of vanadic acid in 70% sulphuric acid. The quantity of vanadic acid reacting with the naphthalene can be determined from the quantity of standard potassium permanganate required to reoxidise the reduced vanadic acid. In the presence of hot concentrated sulphuric acid, naphthalene reduces vanadic acid to the blue divanadyl salt according to the following equations:

$$18H_3VO_4+18H_2SO_4+C_{10}H_8=9V_2O_2(SO_4)_2+C_6H_4(COOH)_2+2CO_2+46H_2O,$$

$$5V_2O_2(SO_4)_2+2KMnO_4+22H_2O=10H_3VO_4+2MnSO_4+2KHSO_4+6H_2SO_4,$$

i.e., 5 molecules Naphthalene=18 molecules $KMnO_4$.

For complete sulphonation the presence of concentrated sulphuric acid is necessary, and in order that the concentration should not be diluted with any water present in the naphthalene, oleum (fuming sulphuric acid) is used. The oxidising temperature should be at least 130° C.

For the determination of naphthalene in the soil, the soil sample is placed in a 500 cc. Erlenmeyer flask and heated in a water bath to 212° F. A stream of air is passed through the soil for 18 hours and carries the naphthalene vapour over to an absorbing tower 5 ft. long, where it is absorbed in concentrated sulphuric acid at 320° F. The tower is then washed out, and the washings and the amount already passed through are made up to a fixed quantity. Aliquot parts are then taken and analysed as described. With 50 mg. naphthalene added to soil the results obtained by this method only varied between 48 and 52·2 mg.

Effect on Soil Micro-organisms.

Tattersfield (1928) found that once soil had been treated with naphthalene, subsequent treatments resulted in the naphthalene disappearing more quickly.

He showed that its decomposition was largely due to the presence of bacteria, which increased in numbers after the first treatment. In organic soils which were rich in these bacteria, naphthalene disappeared more quickly than in soils poor in organic matter. This fact was also noted by Fleming and Baker (1934), but they did not entirely confirm the effect of re-treatment. Making daily analyses, they found that naphthalene of the first treatment disappeared in six days, of the second treatment in four days, and of the third treatment in 16 days.

Effect on Plants.

Although plants cannot be grown in soil containing naphthalene in insecticidal quantities, it is considerably less phytocidal than many other soil fumigants. Fleming and Baker (1934) found even without aeration of treated soil no effect on plants could be discerned one month after treatment.

Experiments in Air.

Tattersfield and Roberts (1920): of uncertain toxicity.

Fleming (1925): minimum lethal dose in air 8 mg./l.; in water 50 mg./l.

Thalenhorst (1937) found 81 mg./l. for 288 hrs. necessary to kill third-instar larvae of the cockchafer (*Melolontha hippocastani*, F.).

Experiments in Soil.

DERMAPTERA.

Steinweden (1934) found 1 oz. (28 gm.) naphthalene flakes per ball for 48–96 hrs. did not kill earwigs (*Forficula auricularia*, L.) in balled nursery stock.

THYSANOPTERA.

Richardson and Nelson (1933) found one or two applications of naphthalene to the soil just after planting gladiolus corms at 2 oz. (56 gm.) per 50 corms was not effective in controlling the gladiolus thrips (*Taeniothrips gladioli*, Mlt. & Stnw.). It also retarded the growth of the plants.

HEMIPTERA.

Coccidae.

Hosni and Shafik (1935) obtained 99–100% kill of *Pseudococcus brevipes*, Ckll., on the roots of *Phoenix* sp. by the application of 2–10 gm. naphthalene per pot to the soil just before repotting.

Aphidae.

Theobald (1925) recommended naphthalene to destroy infestations of the French bean root aphis (*Geoica phaseoli*, Pass.) and lettuce root aphis (*Pemphigus bursarius*, L.) after the plants had been removed.

LEPIDOPTERA.

Hepialidae.

Wilson (1934) recommended naphthalene at 1–2 oz./sq. yd. (34–68 gm./sq. m.) for the control of swift moth larvae (*Hepialus lupulinus*, L.) attacking irises. According to an anonymous publication (Ministry of Agriculture, 1933) such larvae are particularly susceptible to naphthalene.

Aegeriidae.

Blakeslee (1919) stated that naphthalene did not vaporise sufficiently quickly to be effective in peach tree borer (*Aegeria exitiosa*, Say) control. Peterson (1923 *a*) and Snapp (1932) confirmed its ineffectiveness, Peterson obtaining only 3% kill with ½ oz. (14 gm.) per tree. On the other hand, Stear (1933), using ½, 1 and 2 oz.

(14, 28 and 56 gm.) per tree, heaped against the bases of the trees and not covered, found only one larva on nine treated trees, compared with 17 larvae on four untreated trees. In both cases eggs had been previously placed on the trees to ensure infestation, but there was a heavy natural mortality. The trunks of the trees were scorched, especially when naphthalene was applied directly to them.

Noctuidae.

Stear (1933) treated Kentucky blue grass lawns with refined naphthalene at 200, 400 and 600 lb./ac. (22, 45 and 67 gm./sq. m.). The day after application, vials containing cutworms (and also wireworms) were laid on the ground at the base of the grasses for three hours; later all the larvae were dead on the 600 lb./ac. plot and 66% dead on the 200-lb. plots. There was no injury to the grass, but white clover was killed.

COLEOPTERA.

Scarabaeidae.

Melolontha melolontha, L. (Cockchafer).

Decoppet (1920) at 200 gm./sq. m., Marié (1926) at 30 gm./sq. m. and Theobald (1927) up to 6 cwt./ac. (76 gm./sq. m.) found naphthalene ineffective for the control of the larvae of this beetle. On the other hand, Guyot (1926) stated that it was very effective at 30 gm./sq. m., and Thompson (1934) obtained a satisfactory control at 5–6 cwt./ac. (63–76 gm./sq. m.) after the naphthalene had been worked in or washed in by rain. After ploughing out grassland, even 3 cwt./ac. (38 gm./sq. m.) gave good control under favourable conditions. (The garden chafer, *Phyllopertha horticola*, L., was also present in these experiments.)

Phyllopertha horticola, L. (Garden Chafer).

Walton (1935) was able to reduce a grassland population of one million to the acre in October to 174,000/ac. in November and 6,500/ac. in May with a top dressing of 2 cwt. crude naphthalene/ac. (25 gm./sq. m.). Bennett (1940) recorded kills of 12, 45 and 60% respectively on grass plots artificially infested with these larvae with whizzed naphthalene at 2, 4 and 8 cwt./ac. (25, 50 and 101 gm./sq. m.).

Other Scarabaeid Larvae.

To disinfest potting soil for quarantine purposes the U.S. Department of Agriculture (1929 and 1939 *b*) specify 5 lb. of flake naphthalene/cu. yd. (3,000 gm./cu. m.) for the control of larvae of *Popillia japonica*, Newm., *Anomala orientalis*, Waterh., and *Aserica castanea*, Arr. The temperature should not fall below 50° F. and the soil should not be wet. The fumigant should be thoroughly mixed with the soil and left undisturbed for one week. For plant beds (1934 and 1939 *b*) naphthalene should be applied at 2,000 lb./ac. (224 gm./sq. m.) incorporated in the top 3 ins. (7·5 cm.). This method had previously been advocated by Fleming and Baker (1930).

Cottier (1932) found that naphthalene at 3–4 oz./sq. yd. (102–136 gm./sq. m.) worked into the top 3 ins. (7·5 cm.) of soil gave satisfactory control of the New Zealand grass grub (*Odontria zealandica*, White). Muggeridge (1934), however, stated that naphthalene was ineffective for this insect, and plants placed in the soil treated with more than 3 oz./sq. yd. (102 gm./sq. m.) were liable to injury.

Elateridae.

Tattersfield (1928) drew attention to the repellent action of naphthalene on wireworms, which caused the insects to move away from treated soil before a lethal concentration was attained. This effect must complicate the interpretation of experiments in which the result is recorded solely in terms of the crop, though even direct sampling methods which determine the numbers of the insects may be misleading if the wireworms go down below the normal sampling level.

Gray and Wheldon (1919) stated that naphthalene up to 5 cwt./ac. (63 gm./sq. m.) did not even appreciably reduce the numbers of wireworms in a field experiment. Marlatt (1933) mentioned experiments carried out in the Pacific North West in which 85–95% kills of wireworms in test plots were obtained with naphthalene at 800 lb./ac. (90 gm./sq. m.) mixed with the top 10 ins. (25 cm.) of soil. Glen *et al.* (1936) obtained 95% kill of wireworms with 700–750 lb./ac. (78–84 gm./sq. m.) evenly distributed along the plough furrows and worked in. Strong (1936) recorded kills of 95–99% with crude naphthalene at this rate and also (1937) 92% kill of wireworms (*Pheletes californicus*, Mannh., and *P. canus*, Lec.) attacking onions. Morrill and Lacroix (1938), after treating soil with flake naphthalene at 800 lb./ac. (90 gm./sq. m.) and setting out tobacco plants in it afterwards, found 0·47 wireworms/cu. ft. in the treated soil and 1·65 wireworms/cu. ft. in the untreated soil. All these workers stressed the advisability of the soil temperature being at least 70° F. Hawkins (1936) obtained inconclusive results in field tests up to 600 lb./ac. (67 gm./sq. m.), as numbers of wireworms in the untreated plots decreased as much as those in the treated plots.

In Australia, Jarvis (1925 *a*) stated that crude naphthalene at 3 cwt./ac. (38 gm./sq. m.) was quite effective against wireworms in sugar-cane, but McDougall (1934) found two applications of 600 or 800 lb./ac. (67 and 90 gm./sq. m.), one applied to the soil surrounding the sets at planting time, and the other at the time the sets were becoming attractive to the wireworm, did not prevent attack by the wireworm, *Lacon variabilis*, Cand. Ladell (1938), in a field experiment, obtained a 60% reduction of wireworms (*Agriotes* sp.) with 10 cwt. of whizzed naphthalene/ac. (126 gm./sq. m.) applied in April. Gough (1942), however, under practically the same conditions, except that the fumigant was applied in February, obtained no reduction with 15 cwt./ac. (189 gm./sq. m.). In pot experiments of six-days' exposure he found a rate of 25–30 cwt./ac. (315–378 gm./sq. m.) necessary to give high kills (80–100%) with pure naphthalene; whizzed naphthalene at the same rate only gave 45% kill. Miles and Cohen (1938) found crude naphthalene at 3 cwt./ac. (38 gm./sq. m.) applied to potato plots before ridging up had no appreciable effect on the amount of wireworm injury, nor was any injury to the plants by the naphthalene noticed up to 6 cwt./ac. (76 gm./sq. m.). Later (1939) they reported that a naphthalene-fuller's earth mixture at 3 cwt./ac. was also ineffective, but added to mustard dross (*q. v.*) and applied at 1 ton/ac. (20 gm. naphthalene/sq. m.) it was more effective than the mustard dross alone.

Massee (1940) was able to control *Agriotes lineatus*, L., attacking roots of hops by lightly forking crude commercial naphthalene at 4 cwt./ac. (50 gm./sq. m.) around the hills.

Curculionidae.

Isaac (1923) was unable to control the turnip gall weevil (*Ceuthorrhynchus pleurostigma*, Marsh.) on spring cabbages with naphthalene diluted with nine times its weight of neutral powder at 5 lb./rod (8 gm./sq. m.). This measure was probably intended to act as a deterrent to the ovipositing adults rather than as a soil fumigant. Anderson (1929) recommended that crude flake naphthalene should be well mixed with soil at 1 lb./20 sq. ft. (243 gm./sq. m.) to prevent injury to primulas from vine weevil grubs (*Otiorrhynchus sulcatus*, F.). F. F. Smith (1932) found it ineffective, but the soil was treated 30 days before the larvae were introduced, and the chemical may have vaporised. Hardouin (1931) also advised the mixing of powdered naphthalene with potting soil before potting cyclamens and primulas to prevent attack by *Otiorrhynchus rugosostriatus*, Goeze.

Cerambycidae.

Chamberlin (1925) stated that crude naphthalene at 8–16 oz. (227–454 gm.) per plant had little effect on the gooseberry root borer (*Xylocrius agassizii*, Lec.) and destroyed the bushes.

Cryptophagidae.

Edwards and Thompson (1934) found that neither whizzed naphthalene nor drained creosote salts, both at 3 cwt./ac. (38 gm./sq. m.), broadcast and ploughed in, to control the pigmy mangold beetle (*Atomaria linearis*, Steph.) had any significant effect on the crop yield compared with the control.

DIPTERA.

Tipulidae.

Hodson and Beaumont (1926) obtained 95% control of leatherjackets (*Tipula oleracea*, L., and *Tipula paludosa*, Mg.) on cereals in spring with naphthalene at 2 cwt./ac. (25 gm./sq. m.). On strawberries the treatment was not successful. Dawson (1932) found crude and whizzed naphthalene applied to lawns at 2–3 oz./sq. yd. (68–102 gm./sq. m.) and watered in brought leatherjackets (*Tipula* sp.) to the surface, where they could be swept up. The results of the treatment were, however, somewhat variable.

Cecidomyiidae.

Barnes and Theobald (1927) suggested naphthalene at 4 oz./sq. yd. (136 gm./sq. m.) to destroy pupae of *Dasyneura arabis*, Barnes, hibernating in the soil. It was stated in an anonymous paper (New York 1937) that crude naphthalene applied to the soil under pear trees was ineffective in the control of pupae of the pear midge (*Contarinia pyrivora*, Ril.), although previously (New York, 1934) it was referred to as promising.

Chironomidae (?).

Fulton (1933) found naphthalene the most effective of several remedies tried for the control of midge larvae in tobacco seed beds. At 1½ lb./100 sq. yd. (72 gm./sq. m.) satisfactory control was obtained in the field and plants were uninjured.

Psilidae.

K. M. Smith and Wadsworth (1921) found five applications of 1 oz./sq. yd. of equal proportions of naphthalene and soap powder (17 gm. naphthalene/sq. m.) to carrots resulted in 71% carrots free from injury by *Psila rosae*, F., whereas all the control plants were attacked. The effect was probably repellent to the fly rather than lethal to the larvae. Glasgow (1931) also found naphthalene effective for this purpose, and recommended four to six applications of 400 lb./ac. (45 gm./sq. m.) at weekly intervals. He found crude naphthalene more effective than refined. Six applications resulted in 98% carrots free from attack.

Anthomyiidae.

The use of naphthalene here again is probably largely as a deterrent to the adult flies, though it may also have some ovicidal or larvicidal action.

Hylemyia brassicae, Bch. (Cabbage Root Maggot).

Slingerland (1894) referred to the use of naphthalene for controlling this insect. Although it killed the maggots, the plants were injured. Britton and Lowry (1916), using naphthalene in the form of moth balls, only reduced the percentage of cabbages attacked from 23·3% in the controls to 17·5% in plants treated with one moth ball per plant. Brittain (1923) recorded crude naphthalene as giving promising results in the control of this pest. Krasnyuk (1931), with five to six applications of 0·8 gm./plant at 7–8-day intervals, reduced the percentage infestation from 14·1 in the controls to 2·5 in treated plants. Edwards (1932), using drained creosote salts at ¼ oz. (7 gm.) per plant at 7–10-day intervals, reduced the attack by 36%. Goffart (1932 and 1933) also obtained successful results with two applications of 40 and 20 gm./sq. m., with an interval of 10 days between them.

For the onion fly (*Hylemyia antiqua*, Mg.), K. M. Smith and Wadsworth (1921), using naphthalene and soap powder as described for the carrot fly, obtained increased yields of onions over the control.

Trypetidae.

Wiesmann (1934) obtained only 20–40% mortality of cherry fly pupae (*Rhagoletis cerasi*, L.) with two applications to the surface of the ground at 100 gm./sq. m. To the larvae, however, 150 gm./sq. m. was toxic for nine days after treatment. Thiem (1934) also found pure naphthalene at 490 gm./sq. m. and crude naphthalene at 70 gm./sq. m. ineffective in controlling the pupae.

HYMENOPTERA.

Formicidae.

Walker and Anderson (1937) found naphthalene flakes gave promise in the control of the pavement ant (*Tetramorium caespitum*, L.) attacking egg-plants, but retarded the growth of the plants if placed too near the roots.

ISOPODA.

Speyer and Owen (1924) found naphthalene at 1/195 in 250 gm. of soil killed cucumber house woodlice (*Armadillidium speyeri*, Jackson) up to one day after treatment, but all toxic effect had disappeared after four days.

MYRIOPODA.

In an anonymous publication (Pennsylvania 1925) it was recorded that a soot-naphthalene-sand mixture at 150 lb. soot and naphthalene/ac. (17 gm./sq. m.) worked into the soil before sowing lettuce in cold frames had effectively prevented attack by millepedes. MacLeod and Butcher (1934) were unable to obtain satisfactory control of the millepede, *Cylindroiulus londinensis coeruleocinctus*, Wood, attacking potato tubers, with naphthalene at 300–600 lb./ac. (34–67 gm./sq. m.) worked into the soil before planting. Speyer (1934) obtained complete mortality of the millepede, *Blaniulus guttulatus*, Bosc, in soils of tomato houses and chrysanthemum pots when naphthalene was incorporated at the rate of one part to five-hundred parts of soil. Millepedes introduced four days after treatment were unaffected. Broadcast on the surface at 4 oz./sq. yd. (136 gm./sq. m.) and watered in, it killed all millepedes to a depth of 3 ins. (7·5 cm.) in nine days, but only 50% of those from 3–5 ins. (7·5–12·5 cm.) deep. A larger amount, 6–8 oz./sq. yd. (204–272 gm./sq. m.) was therefore recommended. Orchard (1937) for this millepede, and also for *Orthomorpha gracilis*, Koch, attacking cucumber roots, found that naphthalene applied to beds as a fine dust and watered in gave promising results.

Scutigerella immaculata, Newp. (Glasshouse Symphylid).

In an anonymous publication (Oregon 1928) it was found that crude naphthalene at ½ lb./1,000 sq. ft. (2·5 gm./sq. m.) gave no control of the Symphylid. Kearns and Walton (1933) also found "liberal applications" of naphthalene ineffective. Michelbacher (1932) obtained an average of 79% kill in small plots with naphthalene at 1,200 lb./ac. (134 gm./sq. m.), though there was considerable variation between replicate tests.

ACARINA.

Massee (1934) used naphthalene successfully to reduce the infestation of red spider (*Tetranychus telarius*, L.) on hops with applications of 3–4 cwt./ac. to the soil where they were hibernating in colonies round the hills.

MISCELLANEOUS.

Theobald (1923) and many standard textbooks and advisory leaflets recommend naphthalene at 3 cwt./ac. (38 gm./sq. m.) for the control of various soil pests such as leatherjackets (Tipulids), cutworms (Noctuids), chafer grubs (Melolonthids), wireworms (Elaterids), and millepedes (Myriopods).

SUMMARY.

In common with most soil fumigants, naphthalene has given somewhat inconsistent results. It is admittedly liable to be a rather variable product, but it is doubtful if this is the whole explanation. Soil temperature is possibly an important factor, and also the fact that naphthalene has a strong repellent action even at low concentrations. This probably often results in the apparent disappearance of the pest without actually killing it. Rates of application range between 30 and 400 gm./sq. m., but about 100 gm./sq. m. has often given satisfactory results.

Naphthalene applied in a Liquid Medium.

Emulsions of oil solutions of naphthalene were first tested as contact sprays (Richards 1915), and later they were developed as soil insecticides as a convenient method of applying naphthalene to the soil in a finely divided, and presumably, therefore, a more effective state.

Krauss (1931) made a solution of 1 kg. naphthalene in 3 litres carbon disulphide miscible with water by adding a litre of oil-soap spirit. Used in water at a dilution of 1% and at 4 litres/sq. m. (8 gm. naphthalene/sq. m.), 38 out of 40 larvae of *Agrotis segetum*, L., were killed in a pot experiment. The same strength killed vine weevil larvae (*Otiorrhynchus sulcatus*, F.) without damaging the plants on which they were feeding (cyclamens and primulas), whereas a 1% solution of carbon disulphide was ineffective and also damaged the plants. For wireworms 2 and 3% solutions at 5 l./sq. m. were found necessary. After dilution, some of the naphthalene was liable to crystallise out. Miles and Cohen (1939) tested a similar mixture emulsified with Turkey red oil (sulphonated castor oil) on wireworms (*Agriotes* sp.) using up to 8 fl. oz. of carbon disulphide and 8 gm. of naphthalene/sq. yd. (12 gm. and 10 gm./sq. m. respectively). Applying 1 gal./sq. yd. of the diluted emulsion, they reported negative results. All wireworms were killed within six days with emulsions containing 16 and 32 oz. of carbon disulphide (10 and 20%) and 16 and 32 gm. naphthalene/sq. yd. (24–48 and 19–38 gm./sq. m. respectively). Gough (1942) also reported that such mixtures gave improved results both in enhanced toxicity and increased period of effectiveness, compared with pure carbon disulphide emulsion.

Pepper (1937) obtained high kills (83 and 89%) of wireworms attacking brassicas with 1 gm. naphthalene dissolved in $\frac{1}{8}$ fl. oz. (4 cc.) carbon disulphide diluted to 1 U.S. pint, which was the amount applied to each plant. A carbon disulphide emulsion alone containing $\frac{1}{4}$ fl. oz. (8 cc.) gave only 7% kill. Snapp (1932) emulsified a solution of naphthalene in cotton-seed oil. Used as a spray around the base of peach trees, it was ineffective as a remedy for peach tree borer (*Aegeria exitiosa*, Say).

Hammer (1934) used a saturated solution of naphthalene in kerosene, emulsified with finely divided clay and diluted to 25–50% kerosene at 1 U.S. qt./sq. ft., to destroy apple maggots (*Rhagoletis pomonella*, Walsh) pupating in the soil. He obtained 97·3–100% kills, although a 10% solution of kerosene alone gave 95·7% kill.

Burns (1926) and Jarvis and Burns (1926) described experiments to control the sugar-cane grub (*Dermolepida albohirtum*, Waterh.) with a saturated solution of naphthalene in benzene, applying four injections per stool each of $\frac{1}{8}$–$\frac{1}{4}$ fl. oz. Burns stated that the results were promising, though Jarvis and Burns only obtained a 16·6% reduction compared with the controls, only a slightly better result than that obtained with benzene alone.

Summary.

These mixtures must be regarded as a very promising line of investigation in research on soil insecticides, though, like all liquids, they can only have a very limited application.

Sodium Cyanide (NaCN).

Crystalline.

When sodium cyanide reacts with water or acids, hydrogen cyanide gas is given off according to this equation:—$NaCN+H_2O=HCN+NaOH$. Cyanides are highly poisonous, both to human beings and stock, and should be handled carefully. If it is necessary to handle it indoors a respirator should be worn.

Application.

The sodium salt is more frequently used in solution than the calcium one. It has principally only been used on an experimental scale, applied broadcast, and dug, ploughed or harrowed in. Davis (1920 *b*; see under Scarabaeidae) has described a method of distributing it in solution over large areas.

Toxicity to Plants.

Cyanides are highly toxic to plant life, but this effect disappears after a certain period which will depend on the circumstances. The minimum and maximum times found for this disappearance are 7 and 42 days.

Experiments in Air.

Melander (1924) found that sodium cyanide generated the toxic gas very slowly, and when the gas was allowed to pass through a jar of soil it took half a day to kill the test insects (bean weevils), compared with 28 minutes for calcium cyanide.

Fleming (1925): minimum lethal dose in air 8 mg./l.; in water 150 mg./l.

Experiments in Soil.

ORTHOPTERA.

Gryllidae.

Watson (1925) found 1 oz. of cyanide in 2 U.S. gals. water (3·7 gm./l.) was an effective and cheap remedy for various species of mole-crickets attacking vegetable crops. Doucette and Smith (1926) obtained complete mortality of the Surinam cockroach (*Pycnoscelus surinamensis*, L.) in a pot experiment, using a solution of 0·1 gm. cyanide in 100 cc. water applied to 400 gm. soil. 1–2·5 gm. at the roots of roses usually gave kills between 90 and 100%.

ISOPTERA.

Pomeroy (1927) stated that after nests of termites had been destroyed over a large area in the Gold Coast, the land was ploughed and successfully disinfested with sodium cyanide at 160 lb./12,000 gals. water/ac. (18 gm./sq. m.). This rate was also recommended by McDaniel (1934) for the control of termites in Michigan.

HEMIPTERA.

Coccidae.

Pickel (1928) controlled various Coccids on roots of coffee bushes by watering the roots with a 0·3% solution of sodium cyanide, using 9 litres per bush.

Aphidae.

Leach (1918) was unable to kill woolly apple aphis (*Eriosoma lanigerum*, Hsm.) at lower soil depths with a solution of ½ oz. of cyanide/4 U.S. gals. (0·9 gm./l.). Greater amounts than this killed the apple trees.

LEPIDOPTERA.

Aegeriidae.

Peterson (1920) obtained 75–90% kill of the peach tree borer (*Aegeria exitiosa*, Say) by the application of 1 oz. of granular sodium cyanide (or a solution of 1 oz./ U.S. gal.) 2 ins. (5 cm.) deep round the base of the peach trees and covered with a mound of soil.

Crambidae.

Noble (1932) found 1 oz./5 U.S. gals. (1·5 gm./l.) applied to turf at the rate of 2½ U.S. gals./sq. yd. (17 gm./sq. m.) was ineffective in controlling sod webworms.

COLEOPTERA.

Scarabaeidae.

Davis (1920 *b*) stated that sodium cyanide applied dry was not in general so effective as the same amount applied in solution. For the treatment of large areas he described the use of 600-gallon tanks mounted on heavy wagon frames and drawn by a tractor. The tanks were fitted with perforated pipes through which the solution flowed by gravity. For economical operation he advised three tanks and two tractors. This avoided delay while the tanks were being filled. This outfit could cover three acres in a day, applying 165 lb. in 12,000 U.S. gals./ac. (18 gm./sq. m.). No injury was caused to grass except a slight temporary burning, but cultivated crops were appreciably injured. Chemical analyses showed that all the cyanide had disappeared from the soil in 7–10 days, or even less if rain fell. This treatment applied to grassland resulted in 90–100% kill of the Japanese beetle (*Popillia japonica*, Newm.). At 110 lb./ac. (12 gm./sq. m.) the burning of the grass was very slight, and almost as good a kill as at the higher rate was obtained under favourable conditions.

Leefmans (1915) only obtained kills of 11% and 24% of cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.) with a solution of 200 gm./l., applying 20 and 40 cc., respectively, in holes around the cassava plant. Leach and Thomson (1921) found the dipping of soil balls in a solution of sodium cyanide of 3·5 gm./U.S. gal. (0·9 gm./l.) ineffective for the control of Japanese beetle grubs (*Popillia japonica*, Newm.). Fleming (1926 *b*) in small-scale pot experiments was able to kill the adult beetles by placing them for periods of 6–30 hrs. in soil watered with a solution of cyanide of 2 gm./l. Zappe and Garman (1925) were able to kill larvae (except those deeper in the soil) of the Oriental beetle (*Anomala orientalis*, Waterh.) in lawns with a solution of cyanide applied at ⅛–⅜ oz./sq .yd. (4–13 gm./sq.m.), but the grass was scorched. Franklin (1925) found that 1 oz./20 U.S. gals. (0·37 gm./l.) applied at 1 U.S. gal./sq. ft. (15 gm./sq. m.) killed the cranberry root grub (*Amphicoma vulpina*, Hentz). Filinger (1931 *a*) recorded good results in the control of white grubs (*Lachnosterna* sp.) in flower gardens by sprinkling the soil with a solution of 8–10 oz./50 U.S. gals. (1·5 gm./l.) at 2½ U.S. gals./sq. yd. (15 gm./sq. m.).

Elateridae.

Hyslop (1914) stated that cyanide could not be placed in the soil at sowing time or during cultivations immediately afterwards, owing to its toxicity to plants, which lasted for 26–42 days. Cyanide placed in the hills of established maize and potato plants at 150 and 300 lb./ac. (17 and 34 gm./sq. m.) appeared to destroy wireworms (*Agriotes mancus*, Say). French (1916) obtained 92–99% kills of wireworms (mainly *Pheletes californicus*, Mannh.) with ½–5 oz./10 cu. ft. to a depth of 1 ft. (15–150 gm./sq. m.) applied 8 ins. (20 cm.) deep and 4 ins. (10 cm.) from the plant. The application was followed by rolling. Using split beans drilled into the soil as a bait, he obtained 35–80% kills with 1/10 oz. sodium cyanide/linear foot (3 gm./m.) drilled two weeks later 4 ins. (10 cm.) each side of the bait rows and 4 ins. (10 cm.) deep. Peterson (1917) obtained promising results in pot experi-

ments on wireworms with sodium cyanide applied in solution and as a solid at the rate of 100–250 lb./ac. (11–28 gm./sq.m.) for an exposure of seven days. Field experiments, however, in which the cyanide was applied in the plough furrow at 100 and 150 lb./ac. (11 and 17 gm./sq. m.) in solution (10 lb./50 U.S. gals. or 2·4 gm./l.) gave very unsatisfactory results. Finally, 300 lb./ac. (34 gm./sq. m.) in solution was poured on the hills, and this apparently killed all the larvae, but the treatment was much too expensive for normal use.

Ladell (1938) applied a proprietary mixture of sodium cyanide and magnesium sulphate in the plough furrow at 7·5 cwt./ac. (94 gm./sq. m.) and obtained a 45% reduction of wireworms (*Agriotes* sp.). The wireworms on the control plots were reduced by 23%. A similar mixture had previously been recommended by Kaufmann and Sargent (Davis 1920 *a*) using 400 lb. cyanide to 5–600 lb. ammonium sulphate per acre. In addition to acting as a fertiliser, the sulphate assisted in the rapid decomposition of the cyanide.

Curculionidae.

Crowley (1923) found a solution of sodium cyanide (1 oz./15 U.S. gals. or 0·5 gm./l.) applied at 1 U.S. gal./sq. ft. (20 gm./sq. m.) to give effective control of the grubs of *Otiorrhynchus ovatus*, L., and *O. sulcatus*, F., attacking cranberry roots. The same author confirmed the value of cyanide solutions in the control of these cranberry pests and recommended 3 oz. (1939) and 6 oz. (1941) per 100 U.S. gals. (0·2 and 0·4 gm./l.) in sufficient amounts to penetrate the soil to a depth of 3–4 ins. (7·5–10 cm.). F. F. Smith (1932), however, was unable to control third- and fourth-instar grubs of *O. sulcatus* with solutions of varying concentrations without killing the primulas and cyclamens which they were attacking.

Chrysomelidae.

Peterson (1921 *a*) obtained complete kills of the strawberry root worm (*Paria canella*, F.) attacking roses in a greenhouse with solutions of 3 gm./4 U.S. pints/bush, each covering an area of about one square foot (32 gm./sq. m.), but the bushes were injured if more than 1 gm./sq. ft. (11 gm./sq. m.) was used. The injury to the plants was reduced by using less water, but the solution probably did not then penetrate sufficiently to kill the deeper grubs. Weigel and Doucette (1922) found a solution of cyanide applied at 0·45–1·77 gm. per plant gave 77% kills of these grubs, but it injured the roses which they were attacking.

Cerambycidae.

In an anonymous publication (New Mexico 1935) it was found that 1 oz./U.S. gal./cu.ft. (1 kg./cu. m.) was ineffective in the control of larvae of *Prionus californicus*, Motsch., buried in trenches in artificial bark shelters.

DIPTERA.

Trypetidae.

Thiem (1934) found that 150 cc. of a solution of cyanide (10 gm.) and ammonium sulphate (5 gm.) in 1½ l., applied to wooden cages 1/7 sq. m. in area (7gm./sq. m.), was one of the most satisfactory methods tried for the control of pupae of the cherry fly (*Rhagoletis cerasi*, L.).

MYRIOPODA.

Horsfall and Eyer (1921) controlled millepedes attacking seedlings in cold frames with cyanide at 150 lb./ac. (17 gm./sq. m.) sprinkled in furrows and covered over with soil. This treatment resulted in 736 plants compared with 480 in the control. 250 lb./ac. (28 gm./sq. m.) retarded germination.

MISCELLANEOUS.

Hinds (1919) recommended a solution of 1 oz. sodium cyanide/8 U.S. gals. (0·9 gm./l.) at 1 oz./10–12·5 sq. ft. (30 gm./sq. m.) for the control of soil pests of all kinds. Muir and Swezey (1926) found 900 lb./ac. (100 gm./sq. m.) an effective general fumigant in fallow ground. They did not recommend it, however, as it left a residue of free alkali in the soil.

SUMMARY.

The recorded range varies from 4–150 gm./sq. m., the great majority of authors using 15–20 gm./sq. m., generally with satisfactory results. It usually been applied in solutions ranging from 0·2–7·4 gm./l. and usually between 1·0 and 1·5 gm./l.

OTHER SUBSTANCES TESTED AS SOIL INSECTICIDES.

(In alphabetical order.)

Except where otherwise stated, experiments in soil are implied. The prefixes ortho-, meta-, and para- are ignored so far as alphabetical arrangement is concerned.

Acetaldehyde (CH_3CHO).

Liquid. S.G. 0·806 at 0° C.

COLEOPTERA.

Scarabaeidae.

Davis (1920 *a*) found acetaldehyde in water at dilutions of 1/48 and 1/96 applied at 5,000 U.S. gals./ac. (78 and 39 gm./sq. m.) quite ineffective for the control of Japanese beetle grubs.

Acetic Acid (CH_3COOH).

Liquid. S.G. 1·051 at 20° C.

COLEOPTERA.

Scarabaeidae.

Mitchell (1939) reported that seed-beds treated immediately after planting in the spring with 0·8% solution of acetic acid at 0·75 U.S. qt./sq. ft. (6 gm./sq. m.) to control damping off remained free from *Lachnosterna* grubs, whereas untreated beds were seriously damaged. It was later shown that other insects and earthworms were also killed by the treatment.

Acetone (CH_3COCH_3).

Liquid. S.G. 0·792 at 20° C.

Experiments in Air.

Fleming (1925): minimum lethal dose=90 mg./l.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) found that 2 cc. acetone injected into the soil ball of an acacia plant in a 200-cc. pot killed the root mealybug, *Rhizoecus terrestris*, Newst., without injuring the plant.

Acetyl Toluidine ($CH_3 . C_6H_4NHCOCH_3$).

o- and p- forms both crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found that acetyl o-toluidine killed Japanese beetle larvae (*Popillia japonica*, Newm.) in soil when mixed with it at the rate of 0·16% by weight for an exposure of two weeks. For acetyl p-toluidine 0·33% was necessary.

Acetylene (C_2H_2).

Gas. (See also Calcium Carbide, p. 77.)

COLEOPTERA.

Scarabaeidae.

Theobald (1927) found waste acetylene (spent calcium carbide ?) ineffective for the control of cockchafer larvae (*Melolontha melolontha*, L.).

Acetylene Tetrachloride (see Tetrachlorethane).

Alizarin(e) (Dihydroxyanthraquinone) ($C_6H_4(CO)_2C_6H_2(OH)_2$).

Crystalline. Primal colouring matter of madder.

Speyer and Owen (1924) reported that this substance had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when incorporated in the soil up to high rates.

Allyl Isothiocyanate (Mustard Oil) ($CH_2 . CH . CH_2 . NCS$).

Liquid. S.G. 1·017 at 10°C.

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic (0·75).

Lehman (1933) recorded the median lethal dose (50% kill) to the wireworm, *Pheletes californicus*, Mannh., as 0·16 mg./l. for five hours' exposure and 192·9 times as toxic as carbon disulphide.

Thalenhorst (1937) recorded the minimum lethal dose to third-instar larvae of *Melolontha hippocastani*, F., as 3 mg./l. for 24 hours, and 87 times as toxic as carbon disulphide.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Leach and Thomson (1921) only obtained a poor kill of *Popillia japonica*, Newm., grubs in soil balls dipped in a saturated aqueous solution of mustard oil. Fleming (1928) found that the vapour did not penetrate moist soil to kill these grubs so well as carbon disulphide, although it was more toxic than the latter in air and water.

Elateridae.

McDougall (1934) found a 10% dilution placed in the drills with sugar-cane sets, or introduced into the soil close to the set at 1 litre per chain of drill (5 cc./m.), was ineffective as a control measure against the wireworm, *Lacon variabilis*, Cand. Thalenhorst (1937) obtained 97% kill of cockchafer larvae in cages buried 25 cm. deep and within a radius of 14–25 cm. of an injection of 0·5 cc. mustard oil. The substance was also easily emulsified with soap and did not affect one-year-old pines.

See also Mustard, p. 114.

Alum (Potassium Alum) ($Al_2(SO_4)_3K_2SO_4 . 24H_2O$).

Crystalline.

DIPTERA.

Anthomyiidae.

Edwards (1932) gave three applications each of ¼ pint of a solution of 2 oz./gal. to cabbage plants, four days after setting out, without significantly affecting the numbers of plants attacked by the root fly (*Hylemyia brassicae*, Bch.).

Aluminium Salts (see Arsenates, p. 72 and Fluorides, p. 95).

p-Amino Acetanilide ($NH_2 . C_6H_4 . NH . COCH_3$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found 0·5% by weight mixed with soil was toxic to *Popillia japonica*, Newm., grubs for a three-weeks' exposure.

o-Amino Phenol ($NH_2C_6H_4OH$).

Crystalline.

Fleming (1928) found 0·66% by weight mixed with soil was toxic to *Popillia japonica*, Newm., grubs for a three week's exposure.

Ammonia (NH_3).

Colourless gas usually handled in aqueous solution (as ammonium hydroxide), the strength of which is measured in terms of specific gravity. Gas liquor, a crude by-product of the distillation of coal, contains a considerable proportion of ammonia.

Experiments in Air.

Melander (1924) found that the vapour was largely absorbed by the moisture in the soil and that ammonia passed through soil took a relatively long time to kill bean weevils.

Tattersfield and Roberts (1920): moderately toxic.

Experiments in Soil.

HEMIPTERA.

Aphidae.

Bernard (1914) recommended 15–20 gm./sq. m. of crude ammonia for the control of the vine phylloxera.

COLEOPTERA.

Elateridae.

According to Neuweiler (1926) gas liquor at 3,000 and 6,000 l./ha. (300 and 600 cc./sq. m.) had no effect on wireworms.

DIPTERA.

Tipulidae.

Dawson (1932) reported satisfactory control of leatherjackets (*Tipula* sp.) with applications of 1 quart liquid ammonia to 50 gals. water at 1 gal./sq. yd. (about 8 gm. ammonia/sq. m., assuming the original liquid to have been 0·880).

Anthomyiidae.

Brittain (1923) obtained promising results in the control of cabbage root fly (*Hylemyia brassicae*, Bch.) with applications to newly set out plants of an ammoniacal liquor containing 14–15% ammonia.

Trypetidae.

Wiesmann (1934) obtained approximately 90% kill of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) with 10 l./sq. m. of a 25–30% dilution of a gas liquor consisting mostly of ammonia.

MISCELLANEOUS.

Delpont (1926) was able to control cutworms (*Agrotis segetum*, Schiff.), mole-crickets (*Gryllotalpa* sp.) and wireworms by applying crude ammonia to the soil at the rate of 1,800 kg./ha. (180 gm./sq. m.) three to four months before planting out.

Ammonium Carbonate ($(NH_4)_2CO_3$).

Crystalline. Commercial ammonium carbonate is a mixture of the bicarbonate (NH_4HCO_3) and the carbamate ($NH_4NH_2CO_2$).

COLEOPTERA.

Elateridae.

Speyer (1929) applied powdered ammonium carbonate to the surface of the soil at 4 oz./sq. yd. (136 gm./sq. m.) and watered it in well. Young tomato plants placed in the soil four days after treatment were not attacked by wireworms.

DIPTERA.

Mycetophilidae.

Speyer (1923 *a*) found 5% solution ineffective as a control measure for the larvae of *Pnyxia scabiei*, Hopk., in cucumber houses ; a mixture of this and copper sulphate in 2, 1 and ½% solutions (Cheshunt compound?) was equally useless.

Ammonium Bicarbonate (NH_4HCO_3).

Crystalline.

DIPTERA.

Anthomyiidae.

Gasow (1935) found mixtures of ammonium bicarbonate and earth in the proportions of 1/10 and 1/15 killed the eggs of the cabbage root fly (*Hylemyia brassicae*, Bch.), and he recommended that it be applied to the bases of the plants to prevent attack.

Ammonium Sulphate ($(NH_4)_2SO_4$).

Crystalline. Commonly used as a nitrogenous fertiliser.

COLEOPTERA.

Scarabaeidae.

Colón (1919) reported that 1 oz. of sulphate of ammonia mixed with the soil in a flower-pot killed 35 out of 37 white grubs (*Lachnosterna* sp.) within a week. Fleming (1942) obtained only small kills of *Popillia japonica*, Newm., larvae after 14 days' exposure to rates up to 8,000 lb./ac. (900 gm./sq. m.).

Chrysomelidae.

Feytaud (1938) found ammonium sulphate at the rate of 1,600 kg./ha. (160 gm./sq. m.) only caused a slight reduction of pupating larvae of the Colorado beetle (*Leptinotarsa decemlineata*, Say) in pot experiments.

Amyl Alcohol ($C_5H_{11}OH$).

Liquid. S.G. 0·817 at 20° C.

Experiments in Air.

Lehman (1933), using the isomer diethyl carbinol, recorded the median lethal dose (50% kill) to the wireworm, *Pheletes californicus*, Mannh., as 15·67 mg./l. for a five-hour exposure and twice as toxic as carbon disulphide.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) killed root mealybugs (*Rhizoecus terrestris*, Newst.) by injecting 2 cc. of a 5% solution into soil balls of *Acacia* sp.

Amyl Nitrate ($C_5H_{11}ONO_2$) and **Amyl Nitrite** ($C_5H_{11}ONO$).

Liquids.

Experiments in Air.

Tattersfield and Roberts (1920): nitrate, low toxicity (180); nitrite, moderately toxic (64).

Experiments in Soil.

DIPTERA.

Chironomidae.

Speyer (1923 *b*) reported that fumigation of a glasshouse for red spider with amyl nitrate and nitrite brought larvae of the Chironomid, *Orthocladius* sp., in cucumber beds to the surface and killed them.

Amylene Dichloride ($C_5H_{10}Cl_2$).

LEPIDOPTERA.

Aegeriidae.

Snapp and Thomson (1936) found emulsions of amylene dichloride not very toxic to peach tree borers (*Aegeria exitiosa*, Say), but very injurious to the trees.

Aniline ($C_6H_5NH_2$).

Liquid. S.G. 1·022 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (27); Fleming (1925): 22 mg./l. in air; 1020 gm./l. in water.

Experiments in Soil.

DIPTERA.

Anthomyiidae.

K. M. Smith (1923) attempted to control the onion fly (*Hylemyia antiqua*, Mg.) by dusting the young plants with aniline, but the yield of onions on the treated plots was little better than that on the control plots.

***Aniline Hydrochloride** ($C_6H_5NH_2HCl$).*

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·33% by weight of aniline hydrochloride was toxic to *Popillia japonica* larvae for an exposure of one week.

HEMIPTERA.

Coccidae.

Saunders (1926) killed root mealybugs (*Rhizoecus terrestris*, Newst.) with a 2% solution watered on to infested acacia plants.

Aniline Oxalate ($(C_6H_5 . NH_2)_2C_2O_4H_2$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight of aniline oxalate was toxic to *Popillia japonica*, Newm., larvae for an exposure of three weeks

See also Oxanilide.

Anthracene (see Coal Tar Oils, p. 3).

Anthraquinone ($C_6H_4 : (CO)_2 : C_6H_4$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·66% by weight of anthraquinone was toxic to *Popillia japonica*, Newm., larvae for an exposure of three weeks. It was one of the least toxic substances tested.

ISOPODA.

Speyer and Owen (1924) stated that this substance had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when mixed with the soil at high rates.

Arsenical Compounds other than Lead Arsenate (p. 51).

White Arsenic (Arsenious oxide) (As_2O_3).

Amorphous.

COLEOPTERA.

Scarabaeidae.

Illingworth (1921) reported that crude white arsenic at 80 lb./ac. (8 gm./sq. m.) gave good control of the gauger beetle (*Isodon puncticollis*, Mackay) attacking potatoes and sugar-cane in Queensland. The treatment had no deleterious effect on the plants. Jarvis (1933) treated plots of sugar-cane at the rate of 60–200 lb. per acre (7–22 gm./sq. m.), but found living grubs of *Dermolepida albohirtum*, Waterh., still present after four months. Bell (1934) also reported that it was ineffective for the same purpose at similar rates. Wolters (1934), on the other hand, for the control of Oriental beetle larvae (*Anomala orientalis*, Waterh.) attacking sugar-cane in Hawaii, found it as effective as lead arsenate and cheaper, when disc-ploughed and disc-harrowed in sugar-cane fields in Hawaii at one ton per acre (250 gm./sq. m.). In 100 square feet of soil which was excavated to a depth of 12 ins. (30 cm.) there was an average of 87% difference between the number of grubs in the treated and untreated areas. Nichol (1935) obtained only poor control of the fig beetle (*Cotinis*

texana, Casey) with 1 lb. of white arsenic lightly raked into the surface of an area of 400 sq. ft. (2 gm./sq. m.). Fleming (1942) found it about twice as toxic as lead arsenate to *Popillia japonica*, Newm., larvae. He obtained high kills at 1,000 lb./ac. (112 gm./sq. m.). It was effective in the soil for two years, but was highly phytocidal.

Curculionidae.

McDaniel (1932) recovered 76 beetles and pupae of the strawberry root weevil (*Otiorrhynchus ovatus*, F.) attacking conifer seedlings on plots treated with 80 lb./acre (9 gm./sq. m.), compared with a total of 503 beetles and pupae from the control plots.

DIPTERA.

Cecidomyiidae.

Sjöberg (1936) stated that arsenic trioxide in water showed promise in laboratory experiments in the control of larvae of the wheat gall-midge (*Contarinia tritici*, Kby.).

Anthomyiidae.

Brittain (1920) found that a mixture of white arsenic (5%) and clay applied to brassicas at the rate of 700 lb. per acre (4 gm./sq. m.) was ineffective in preventing attack by cabbage root fly (*Hylemyia brassicae*, Bch.). Treated with 5% white arsenic and 40% tobacco dust, only 2% of plants were destroyed by the fly, compared with 17–44% in the controls. In the following year (1921) a similar mixture was not so successful.

Paris Green.

An arsenical pigment, the main constituent of which is a complex compound of copper acetate and copper arsenite, to which the formula $(CH_3COO)_2Cu \cdot 3Cu(AsO_2)_2$ has been given.

LEPIDOPTERA.

Crambidae.

Noble (1932) found that a suspension of 1 lb./50 U.S. gals. (2·4 gm./l.) at the rate of 2 U.S. qt./sq. yd. (5 gm./sq. m.) was ineffective in controlling sod webworms in lawns. North and Thompson (1933), using ½ lb./20 U.S. gals. (3 gm./l.)/1,000 sq. ft. (2·5 gm./sq. m.), found an appreciable reduction in damage done to the turf by the webworms (from 87 units in the control to 35 on the treated plots), but the treatment itself injured the turf.

COLEOPTERA.

Scarabaeidae.

Leefmans (1915) found that Cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.) were all killed when placed in earth containing 1% Paris green. Hermans (1932) found that ¾ kg./100 sq. m. (8 gm./sq. m.) watered on to the soil was successful in controlling May grubs (*Melolontha* sp.) in lawns. Fleming (1942) reported that Paris green was rather more toxic to *Popillia japonica*, Newm., larvae than lead arsenate (high kills obtained at about 2,000 lb./ac. or 224 gm./sq. m.). Synthetic homologues were also tested, and copper oleo-arsenite was found to be more toxic, copper stearo-arsenite equally toxic, and copper lauro-arsenite and palmito-arsenite less toxic than lead arsenate. They were all more phytocidal.

Elateridae.

According to McDougall (1934), 200 lb./ac. (22 gm./sq. m.) incorporated with the soil around sugar-cane sets at planting time was quite ineffective in controlling

the wireworm, *Lacon variabilis*, Cand. Woodworth (1938) found that wireworms were unlikely to take any Paris green into the gut, as the particles would be filtered out by their peculiar feeding mechanism.

Arsenious Sulphide (Orpiment) (As_2S_3).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1942) found it had about the same toxicity as lead arsenate to larvae of *Popillia japonica*, Newm. (*i.e.*, 2,000 lb./ac. or 224 gm./sq. m. to give a high kill), but was less permanent in its action and more toxic to plants.

Sodium Arsenite ($Na_2H. AsO_3$).

Crystalline.

Experiments in Water.

Woodworth (1938) found that wireworms (*Pheletes californicus*, Mannh.) increased in weight when immersed in a solution of sodium arsenite and took in arsenic through the body wall.

Experiments in Soil.

ISOPTERA.

Kofoid (1934) stated that ground treated with 0·1% solution of sodium arsenite at 100 U.S. gals./100 sq. ft. (41 gm./sq. m.) was still free from termites two years later.

COLEOPTERA.

Scarabaeidae.

Leefmans (1915) found that a 2% solution (sodium arsenicum) in soil killed all Cassava grubs (*Leucopholis* and *Lepidiota* sp.) when watered on to the soil.

DIPTERA.

Cecidomyiidae.

Sjöberg (1936) stated that a solution watered on to the earth showed promise in controlling larvae of the wheat gall midge (*Contarinia tritici*, Kby.).

Inorganic Arsenates.

The compounds mentioned under this heading have been mainly tested by a few authors who have compared them with lead arsenate for the control of Japanese beetle and similar insects, and they are more conveniently dealt with together than separately.

COLEOPTERA.

Scarabaeidae.

Leach (1926) stated that basic lead arsenate and magnesium and ferric arsenates were non-toxic to larvae of the Japanese beetle (*Popillia japonica*, Newm.) and also to plants. Calcium arsenate was almost as effective as acid lead arsenate (though more toxic to plants) and zinc and copper arsenates were rather less effective. Fleming and Baker (1936) found zinc and ferric arsenates almost as good as lead arsenate in the control of this same insect. The arsenates of barium and magnesium were also toxic, but aluminium, dicalcium, tricalcium and manganese arsenates gave very inconsistent results. This subject has been further investigated by Fleming (1942), who has carefully compared the toxicity of a number of arsenates to larvae of *Popillia japonica*, Newm. When freshly applied to the soil, significantly less than 1,000 lb./ac. (112 gm./sq. m.) of the arsenates of calcium, magnesium and manganese were required to produce an effect equivalent to that of the standard

1,000 lb./ac. of lead arsenate. The quantities estimated for the arsenates of aluminium, barium, ferric iron and zinc to produce this effect did not appear to differ significantly from 1,000 lb./ac. Acid lead arsenate was also the least detrimental to plants of those arsenates which were toxic to the larvae.

Kerr (1940) found mixtures of magnesium arsenate and sand (1/10 and 1/20) almost as effective as lead arsenate in preventing white grub (*Lachnosterna* sp.) attack on strawberries. The material was placed in the holes (1·5 oz. per hole) made for setting out the plants. Calcium and zinc arsenate used in this manner were highly toxic to the plants.

Ascaridole (see Leach and Johnson (1925) under Wormseed Oil, p. 142).

Barium Chloride ($BaCl_2$).

Crystalline.

Jarvis (1916) applied a solution of 1 lb. in 3 gals. of water for the control of *Dermolepida* grubs in sugar-cane fields with negative results.

For other Barium Salts see Arsenates, p. 72, Fluorides, p. 95, Fluosilicates, p. 95.

Benzal (Benzylidene) Chloride ($C_6H_5CHCl_2$).

Liquid. S.G. 1·295 at 16° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (24).

Benzaldehyde (C_6H_5CHO).

Liquid. S.G. 1·05.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained 44% kill of peach tree borers (*Aegeria exitiosa*, Say) with an application of ½ oz. per tree.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) obtained no kill of *Popillia japonica*, Newm., grubs at the root of perennial plants treated with a saturated solution of benzaldehyde in water; the plants were killed.

Benzene (C_6H_6).

Liquid. S.G. 0·879.

Experiments in Air.

Tattersfield and Roberts (1920), of low toxicity (775).

Experiments in Soil.

ISOPTERA.

Jarvis (1927 *b*), after burning infested sugar-cane stools, destroyed termites remaining in the soil by treating the holes from which the plants had been removed with 1–8 fl. oz. (25–200 gm.) of benzene.

COLEOPTERA.

Scarabaeidae.

Leefmans (1915) only obtained low kills of Cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.) with 40 cc. injections per plant. Jarvis (1925 *b*) obtained

100% kill of third-instar larvae of *Dermolepida albohirtum*, Waterh., with 5 cc. benzene applied to 80 cu. ins. of moist soil and also with ½-oz. doses (14 gm.) poured on to the soil 4 ins. (10 cm.) above the grubs in cages. Jarvis and Burns (1926) only obtained 15% kill of these grubs with ¼-oz. doses.

Elateridae.

Jarvis (1927 *c*) found 22 gals./ac. (22 gm./sq. m.) of benzene, used in conjunction with a bait, sufficient to control wireworms in sugar-cane fields.

Chrysomelidae.

Trappmann (1924) and Feytaud (1932) recommended 4 to 5 litres of crude benzene/sq. m. for the destruction of Colorado beetle (*Leptinotarsa decemlineata*, Say) in the soil.

Staphylinidae.

Vincent (1916) stated that 100 l./ha. (9 gm./sq. m.) gave good control of an unspecified Staphylinid beetle injurious to turnips, but was too expensive for normal use.

DIPTERA.

Mycetophilidae.

Ritzema Bos (1917) found that 5 to 7 cc. injected into holes near gherkin plants effectively controlled injurious *Sciara* larvae.

MISCELLANEOUS.

Ritzema Bos (1898) described experiments in which various soil insects, including wireworms, cutworms and cockchafer larvae, were successfully controlled with benzene injections applied with a "pal" injector. *Otiorrhynchus* larvae, however, survived doses which killed wireworms.

The Addition of other Substances to Benzene.

Naphthalene. Jarvis (1925 *b*) obtained 100% kill of *Dermolepida* grubs with 1/32 fl. oz. (1 gm.) of a solution of naphthalene in benzene applied to 10 cu. ins. of soil. 1/16 fl. oz. (2 gm.) gave a complete kill when applied to 48 cu. ins. within five days. Jarvis and Burns (1926), however, only obtained 17% kill with doses of ¼ fl. oz. in plot experiments.

Pine Tar Creosote. Burns (1929) carried out some inconclusive experiments with 10 and 20% solutions, applying 1/16 fl. oz. (4 gm.) to each side of sugar-cane stools to control *Dermolepida* grubs. In all cases, however, the treated canes were slightly better than the untreated ones.

Commercial Creosote. Burns (1929) also obtained slightly improved results over the controls with 20% solutions of creosote in benzene applied as for the previous substance. Jarvis (1930 *a*) only recorded a 34% kill of grubs with this mixture.

Carbon Disulphide. Davis (1920 *a*) obtained negative results in the control of Scarabaeid grubs (probably *Popillia japonica*, Newm.) with a 1/48 dilution of Kopper's solution, a by-product consisting mainly of carbon disulphide (25%) and benzene (75%) applied at 5,000 U.S. gals./ac. (approximately 80 cc./sq. m.).

Tetrachlorethane. Marchal (1931) found a mixture, advocated by M. Willaume, of equal parts of benzene and tetrachlorethane rendered miscible with water by the addition of 20% sodium sulphoricinate was a very effective soil fumigant

Benzyl Amine ($C_6H_5CH_2NH_2$).

Liquid. S.G. 0·980 at 20° C.

Experiments in Air.

Fleming (1925): minimum lethal dose in air 248 mg./l.

Benzyl Chloride ($C_6H_5CH_2Cl$).

Liquid. S.G. 1·103 at 18° C.

Experiments in Air.

Tattersfield and Roberts (1920): high toxicity (4).
Fleming (1925): minimum lethal dose in air 4 mg./l; in water 36 mg./l

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Fleming (1925, 1928) found it did not kill *Popillia japonica*, Newm., grubs in soil, but (1926) he recorded 3·5 gm./l. of water as the strength of dipping solution necessary to kill the adult beetles at the roots of potted plants.

Benzoyl α-Naphthylamine ($C_{10}H_7NH.CO.C_6H_5$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% benzoyl α-naphthylamine was toxic to *Popillia japonica*, Newm., larvae for an exposure of three weeks.

Bleaching Powder ($CaOCl_2$).

COLEOPTERA.

Elateridae.

Comstock and Slingerland (1892) found it ineffective in controlling wireworms except at the high rate of 6 tons/ac. (1,344 gm./sq. m.).

DIPTERA.

Cecidomyiidae.

Mühlow (1936) reported that the application of 180 lb./ac. of a product containing 43% bleaching powder (9 gm./sq. m.) gave control of the wheat gall-midges, *Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh., in a field experiment.

Borates.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) tested the borates of copper, lead and mercury(ic) as possible substitutes for lead arsenate for the control of *Popillia japonica*, Newm., larvae. In pot experiments at 1,500 lb./ac. (168 gm./sq. m.) only mercuric borate gave successful results. Fleming (1942) made similar tests on the borates of calcium, lead, magnesium, nickel, sodium, strontium and zinc, at rates up to 2,000 lb./ac. (224 gm./sq. m.). Even at the highest dose 30–40% of the grubs survived, and all the borates were very toxic to plants.

Borax (Sodium Tetraborate) ($Na_2B_4O_7$, $10H_2O$).

Crystalline.

ISOPTERA.

Kofoid (1934) stated that plots treated with 5 and 10% solutions of borax remained free from infestation by termites for at least a year, whereas there were many in the surrounding ground.

COLEOPTERA.

Scarabaeidae.

Jarvis (1916) obtained satisfactory control of *Dermolepida* grubs in sugar-cane fields with a solution of 1 lb. in 3 gals. of water, but the treatment was very expensive.

Chrysomelidae.

Weigel and Doucette (1922) obtained negative results in the control of the strawberry root worm, *Paria canella*, F., attacking roses, with applications of 1–2 gm. borax in solution per plant.

DIPTERA.

Anthomyiidae.

Stookey (1919) found application to cabbages of a solution of 1 oz. of powdered borax in 10 U.S. gals. of water was ineffective in controlling cabbage root maggot attack (*Hylemyia brassicae*, Bch.).

Bordeaux Mixture.

Bordeaux mixture is a fungicide made from lime and copper sulphate. As a soil insecticide it has principally been used in mixtures with other substances.

COLEOPTERA.

Scarabaeidae.

Stear (1932) noticed that a mixture of Bordeaux mixture and lead arsenate used in the routine spraying of potatoes noticeably decreased white grub (*Lachnosterna* sp.) injury. This reduction did not occur with lead arsenate alone.

DIPTERA.

Psilidae.

Whitcomb (1938) found a 1% lubricating oil emulsion and 1% oil emulsion in standard Bordeaux mixture applied to carrots was only slightly effective in controlling carrot fly (*Psila rosae*, F.).

Anthomyiidae.

Flint and Compton (1925) found applications of Bordeaux mixture alone and mixed with lubricating oil emulsion or mercuric chloride gave somewhat increased yields of onions when applied to the young plants to control onion fly (*Hylemyia antiqua*, Mg.). Wright (1938 *b*) applied a mixture of 1% lubricating oil emulsion and Bordeaux mixture for this purpose and recorded 47% of the plants remaining in July, a percentage not much higher than that in the control plots (37%).

Borneol (Borneo Camphor) ($C_{10}H_{17}OH$).

Crystalline.

ISOPODA.

According to Speyer and Owen (1924) this substance had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when mixed with the soil at high rates.

Brombenzene (Phenyl-Bromide, Mono-Brombenzene) (C_6H_5Br).

Liquid. S.G. 1·499 at 15° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (96).
Fleming (1925): minimum lethal dose 90 mg./l. in air; 247 mg./l. in water.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) found that 2 cc. injections in the soil killed mealybugs (*Rhizoecus terrestris*, Newst.) without injuring acacia plants.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) found it useless for the control of peach tree borer (*Aegeria exitiosa*, Say) and injurious to peach trees.

Bromoform ($CHBr_3$).

Liquid. S.G. 2·884 at 25° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (94).

Calcium Carbide (CaC_2) (see also Acetylene, p. 66).

Crystalline.

When calcium carbide reacts with water, acetylene gas is given off.

HEMIPTERA.

Aphidae.

Girardi (1916) recommended calcium carbide dug into the soil about 25 cm. deep at the rate of 1 kg./sq. m. to control root Aphids. Lemée (1918) advised a calcium carbide sludge for the control of the woolly apple aphis (*Eriosoma lanigerum*, Hsm.). Three to four litres of a milk of the substance for a good-sized tree should be poured into a hole of about 40 cm. radius dug to expose the roots of the tree.

COLEOPTERA.

Scarabaeidae.

Smith and Hadley (1926) stated that calcium carbide was useless for the control of Japanese beetle larvae. Hengl (1935) also obtained unsuccessful results with it at 330 kg./ha. (33 gm./sq. m.), applied in holes 15 cm. deep, to control Scarabaeid larvae.

Elateridae.

Malenotti (1927) also reported it ineffective for the control of wireworms applied at 3 and 6 quintals/ha. (30 and 60 gm./sq. m.).

Chrysomelidae.

Feytaud (1932) found calcium carbide quite useless for the control of Colorado beetle adults (*Leptinotarsa decemlineata*, Say) up to 4,000 kg. and 20,000 litres of water/ha. (400 gm./sq. m.).

DIPTERA.

Anthomyiidae.

Hille Ris Lambers (1932) mixed 100 gm. calcium carbide with 10 kg. soil and then placed 200 pupae of the beet fly (*Pegomyia hyoscyami*, Panz.) in it. 35 flies emerged, only a few less than those emerging from the control soil (42).

MYRIOPODA.

Brunetau (1935) obtained inconclusive results in the control of the glasshouse Symphylid (*Scutigerella immaculata*, Newp.) applying 400 gm./ha. (40 gm./sq. m.) in holes about 20 cm. deep.

SUMMARY.

Out of the eight references cited, with applications ranging from 30 to 1000 gm./ sq. m., only the highest was reported to give successful results.

Calcium Chloride ($CaCl_2$) (see p. 12).

Crystalline.

COLEOPTERA.

Elateridae.

Comstock and Slingerland (1892) reported that it was not effective in controlling wireworms under 6 tons/ac. (1,250 gm./sq. m.). Hawkins (1936) found it did not kill or check wireworms at 1,000 lb./ac. (112 gm./sq. m.).

Calcium Cyanide (see p. 12).

For other Calcium Compounds see Arsenates, p. 72, Borates, p. 75, Fluorides, p. 95, Fluosilicates, p. 95, Bleaching Powder, p. 75.

Calcium Cyanamide ($CaCN_2$).

Crystalline.

Calcium cyanamide is frequently used as a nitrogenous fertiliser, and for insecticidal use is distributed on the surface by a manure distributor or by hand and ploughed, harrowed or dug into the soil. It is often abbreviated to cyanamide, and it is assumed that references to cyanamide always mean the calcium compound.

Crowther and Richardson (1932) have investigated its effect on germination, nitrification and soil reaction. To make it less dusty to handle it is often mixed with a small quantity of oil.

Experiments in Air.

Fleming (1925): non-toxic at 796 gm./l.

Experiments in Soil.

THYSANOPTERA.

Huber *et al.* (1939) recorded reductions of *Taeniothrips inconsequens*, Uzel, emerging from the soil, of approximately 90% in three prune orchards after treatment of the soil with commercial oiled calcium cyanamide at 300 lb./ac. (34 gm./ sq. m.) in March. Breakey (1942) was able to repeat these results in a wet season and obtained equally high kills with rates as low as 100 lb./ac. (11 gm./sq. m.). Splitting the higher rate into two applications did not improve the kill, but it was useful in that one application could be timed to control the thrips and a second to control the brown rot fungus, *Sclerotinia fructicola*, Wint. Superphosphate at 216 lb./ac. and hydrated lime at 50 lb./ac. applied at the same time as the cyanamide both reduced the kill to about 80%.

HEMIPTERA.

Aphidae.

Reppert *et al.* (1922) found doses up to $6\frac{2}{3}$ oz. (190 gm.) per tree were ineffective for the control of woolly apple aphis (*Eriosoma lanigerum*, Hsm.) on the roots of nursery stock, and also injured the roots.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923*a*) obtained 76% kill of peach tree borers (*Aegeria exitiosa*, Say) with 1 oz. (28 gm.) per tree applied in the usual way.

COLEOPTERA.

Scarabaeidae.

Van Zwaluwenburg (1918) stated that exceptionally heavy dressings, up to 2 lb. (908 gm.) per stool, had no effect on *Lachnosterna* grubs attacking sugar-cane. In an anonymous publication (Porto Rico, 1924) it was stated that it was applied up to 4 oz./sq. ft. (1,220 gm./sq. m.) to soil in boxes and found that although this rate prevented the germination of corn, it did not kill white grubs (*Lachnosterna* sp.), nor did it deter them from entering the treated soil.

Fleming (1942) did not record high kills of *Popillia japonica*, Newm., larvae below the rate of 8,000 lb./ac. (896 gm./sq. m.).

Elateridae.

Malenotti (1927) found it ineffective for the control of wireworms at 5 quintals/ha. (50 gm./sq. m.). Melander (1923) found it completely harmless when applied to wireworms previously concentrated to baits. Hawkins (1936) also found it did not reduce wireworm injury to potatoes when applied at 1,000 lb./ac. (112 gm./sq. m.), and it also affected the stand of the crop. Miles and Cohen (1939) stated that it had no action on wireworms (*Agriotes* sp.) up to 6 cwt./ac. (76 gm./sq. m.).

Chrysomelidae.

Deleuze and Dussy (1939) at 200 and 300 kg./ha. (20 and 30 gm./sq. m.) recorded only moderate reductions in the numbers of Colorado beetle adults (*Leptinotarsa decemlineata*, Say) emerging from treated soil. Feytaud (1939) stated that at the usual agricultural rates of 150 to 500 kg./ha. (15–50 gm./sq. m.) calcium cyanamide had no effect on the pupating larvae of this insect, but at 1,200 to 4,000 kg./ha. (120-400 gm./sq. m.) reductions of 84 to 97%, compared with 47% in untreated soil, were obtained.

Cryptophagidae.

Edwards and Thompson (1934) found no significant difference in the yield of mangolds from plots treated with calcium cyanamide at 6 cwt./ac. (76 gm./sq. m.) to control the pigmy mangold beetle (*Atomaria linearis*, Steph.).

DIPTERA.

Tipulidae.

Maerks (1939) killed all eggs and first-instar larvae, and 50% of second-instar larvae of *Nephrotoma maculata*, Mg., in pot experiments with moorland soil treated at the rate of 3 dz./ha. (30 gm./sq. m.).

Cecidomyiidae.

Schøyen (1932) recorded an increase in the yield of fruit from pear trees after the soil beneath them had been treated with calcium cyanamide at 10 kg./ar. (100 gm./sq. m.) to control the pear midge (*Contarinia pyrivora*, Ril.). Klee and Rademacher

(1935) obtained 52 and 39% kills of wheat gall-midges (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) at 1 dz./ha. (10 gm./sq. m.) and 49 and 61% kill at 2 dz./ha. (20 gm./sq. m.). Mühlow (1936) found calcium cyanamide gave 75% control of these insects applied at 3 dz./ha. (30 gm./sq. m.).

MISCELLANEOUS.

Muir and Swezey (1926) obtained 96% kill of soil insects in fallow soil in Hawaii with an application of 3 U.S. tons/ac. (672 gm./sq. m.) of calcium cyanamide containing 40% calcium cyanide (*sic*).

SUMMARY.

Rates of application range from 10–1,220 gm./sq. m. Satisfactory results at normal agricultural rates (about 30 gm./sq. m.) have in the main been obtained in the control of small insects like thrips and gall-midges.

Calcium Sulphide (CaS) (see also Gas Lime, p. 97).

Crystalline.

COLEOPTERA.

Elateridae.

Regnier (1928) improved a failing crop of wheat which had been attacked by wireworms (*Agriotes obscurus*, L.) by the application of calcium sulphide at 200 kg./ha. (20 gm./sq. m.) mixed with calcium phosphate, but did not consider that the result justified the expense. Gough (1942) did not record any reduction in the number of wireworms on field plots treated with calcium sulphide at 350 lb./ac. (39 gm./sq. m.) broadcast in February and ploughed in.

Calcium Thiocarbonate ($CaCS_3$).

Crystalline.

HEMIPTERA.

Coccidae.

Saunders (1926) stated that a 5% solution of this substance watered on the soil killed root mealybugs (*Rhizoecus terrestris*, Newst.) without injuring acacia plants.

Calomel (see Mercurous Chloride, p. 109).

Camphene ($C_{10}H_{16}$).

Crystalline.

Experiments in Soil.

ISOPODA.

According to Speyer and Owen (1924), camphene mixed with soil at quite high rates had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson).

Camphor ($C_{10}H_{16}O$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Leach and Thomson (1921) reported that it was useless as a soil insecticide for Japanese beetle larvae (*Popillia japonica*, Newm.).

Elateridae.

Britton and Anderson (1926) tested camphor dissolved in wood alcohol as a remedy for *Pheletes agonus*, Say, and other wireworms, but found it of little use.

ISOPODA.

Speyer and Owen (1924) mixed camphor with soil in the proportion of 1/164, and obtained 90% kill of the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) in one to five days. Compared with other substances similarly tested, they found its action rather weak.

Carbon Disulphide (see p. 18).

Carbon Hexachloride (see Hexachlorethane, p. 98).

Carbon Tetrachloride (CCl_4).

Colourless oily liquid. S. G. 1·584.

Owing to its chemical similarity to carbon disulphide, it was only natural that this substance should have been tested as a soil insecticide. It has the advantage of being non-inflammable, and a certain proportion is frequently added to carbon disulphide in order to reduce the risk of fire during transport and storage (Regnier 1939).

Determination (see Daroga and Pollard, 1941 *b*).

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (1600).

Fleming (1925): minimum lethal dose 796 mg./l. Thalenhorst (1937) also found it much less toxic than carbon disulphide to third-instar larvae of the cockchafer, *Melolontha hippocastani*, F., recording the minimum lethal dose as being greater than 1,775 gm./l. for 120 hours.

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Blakeslee (1919) described it as similar to carbon disulphide (which gave rather inconsistent results) in its action on the peach tree borer (*Aegeria exitiosa*, Say). Snapp and Thomson (1934 *a*) found it less effective than ethylene dichloride and more injurious to peach trees.

COLEOPTERA.

Scarabaeidae.

Leefmans (1915) found it less effective than carbon disulphide for the control of the Cassava grubs, *Leucopholis rorida*, F., and *Lepidiota stigma*, F., only obtaining 20 and 30% kills from injections of 20 and 40 cc. per plant, respectively.

Elateridae.

Hawkins (1936) found some wireworms still alive after one month in 9-in. pots treated with ¼ and ½ fl. oz. (approximately 900 and 1,800 gm./sq. m.).

Curculionidae.

Schwardt and Lincoln (1940) obtained 41% kill of larvae of the alfalfa snout beetle, Otiorrhynchus ligustici, L., with 36 cc. doses of carbon tetrachloride injected 15 cm. apart at 4,473 lb./ac. (500 gm./sq. m.).

MYRIOPODA.

Michelbacher (1932) obtained a 59% kill of the glasshouse Symphylid (*Scutigerella immaculata*, Newp.) with carbon tetrachloride injected into the soil 18 ins. (45 cm.) apart at the rate of 290 U.S. gals./ac. (425 gm./sq. m.).

MISCELLANEOUS.

Molz (1911) described carbon tetrachloride as being about as effective as carbon disulphide as a soil fumigant, and when used as an emulsion in water more effective than carbolineums especially for the deeper insects. Melander (1924) found it took twice as long as carbon disulphide to pass through a tube of soil and kill bean weevils encaged in a chamber connected with the tube.

SUMMARY.

The few figures cited are hardly sufficient to suggest a satisfactory rate of application, though the lowest specified rate tested is 425 gm./sq. m. Most authors have compared it with carbon disulphide and found it considerably less toxic.

p-Chloracetanilide ($Cl . C_6H_4 . NH . COCH_3$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% of this substance was toxic to third-instar larvae of *Popillia japonica*, Newm., for an exposure of two weeks.

o- and p-Chloraniline ($Cl . C_6H_4 . NH_2$).

ortho- Liquid. S.G. 1·213 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (19).

para- Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920) : of uncertain toxicity.

Chlorbenzene (C_6H_5Cl).

Liquid. S.G. 1·106 at 20° C.

Experiments in Air.

Fleming (1925): minimum lethal dose 124 mg./l. in air; 366 mg./l. in water.
Tattersfield and Roberts (1920): of low toxicity (200).

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained 100% kill of peach tree borers (*Aegeria exitiosa*, Say) with ½ oz. applications to peach trees, but killed the trees.

Chlorcresol ($CH . C_6H_3(CH_3)Cl$).

COLEOPTERA.

Curculionidae.

Isaac (1923) absorbed 4½ fl. oz. chlor-ortho cresol in 4½ lb. chalk powder and applied the mixture to a plot of spring cabbages one rod in area, with the object of controlling the turnip gall weevil (*Ceuthorrhynchus pleurostigma*, Marsh.); 112 of the 200 treated plants were galled, a number scarcely differing from the 131 galled plants in the control plots.

DIPTERA.

Anthomyiidae.

K. M. Smith (1923) found the application of a dust consisting of chlor-cresylic acid absorbed in chalk to onion beds was one of the most effective treatments tested for the control of the onion fly (*Hylemyia antiqua*, Mg.); a plot thus treated yielded 60 lb. of onions compared with 32 lb. from the control plot. A later experiment (Smith, 1925) gave less successful results, but when the same mixture was applied to cabbage plants to prevent infestation by the root fly (*H. brassicae*, Bch.), no treated plants were attacked, compared with 24 and 30% attacked in the untreated plants. Wright (1938 *b*), however, using three applications of a 1% dust to onions, recorded no improvement over the untreated plots in the percentage of plants surviving in July.

Chloric Acid ($HClO_3$).

This substance does not occur in the pure state and is only known in aqueous solution and in the form of salts.

Rainey (1938) reported that favourable results in the control of cabbage root fly (*Hylemyia brassicae*, Bch., and *H. floralis*, Fall.) have been obtained in Russia with 1/10% solutions of this substance. Walton (1940), however, found it ineffective for this purpose when ¼ pint of a 1% solution was applied to cauliflowers after setting out.

(Mono) Chlornaphthalene ($C_{10}H_7Cl$).

α Liquid. S.G. 1·194 at 20° C.

β Crystalline.

HEMIPTERA.

Coccidae.

Saunders (1926) watered acacia plants infested with the root mealybug (*Rhizoecus terrestris*, Newst.) with a 5% emulsion of mono-chlornaphthalene and killed the Coccids without harming the plant.

ISOPTERA.

Hockenyos (1939) found chlornaphthalene mixed with soil at the rate of 1/1,000 was toxic to termites.

Chloroform ($CHCl_3$).

Liquid. S.G. 1·499 at 15° C.

Determination (see Daroga and Pollard 1941 *b*).

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (1040).

Fleming (1925): minimum lethal dose 796 mg./l. in air.

Leach and Thomson (1921) found saturated solutions of chloroform in water were toxic to larvae of *Popillia japonica*, Newm., dipped in them.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) was able to kill mealybugs (*Rhizoecus terrestris*, Newst.) infesting *Acacia* sp. without harming the plant by injecting 2 cc. chloroform into the soil ball.

Chlorphenol (ClC_6H_4OH).

ortho- Liquid. S.G. 1·241 at 18° C.

para- Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): both highly toxic (6).

Chlorpicrin (see p. 31).

(Mono)Chlortoluene ($ClC_6H_4CH_3$).

Liquids. S.G. ortho- 1·085 at 18° C.; meta- 1·072 at 20° C.; para- 1·071 at 18° C.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (120).

(Mono)Chlorxylene ($ClC_6H_3(CH_3)_2$).

Experiments in Air.

Tattersfield and Roberts (1920): of uncertain toxicity.

Coal Tar Distillates (see p. 33).

Cobalt Compounds.

Lipp (1929) tested the oxide, arsenite, and phosphate of cobalt and also potassium cobaltinitrite as soil insecticides for *Popillia japonica*, Newm., larvae. Applied in flower-pots at the rate of 1,500 lb./ac. (168 gm./sq. m.) they were all ineffective.

Copal Oil.

Saunders (1926) obtained some success in the control of the mealybug (*Rhizoecus terrestris*, Newst.) by watering on emulsions, and with 2 cc. injections, in small pots.

Copper Sulphate ($CuSO_4 . 5H_2O$).

Crystalline.

Experiments in Water.

Leach and Thomson (1921) found a 5% solution was not toxic as a dip to *Popillia japonica*, Newm., larvae. See also Speyer (1923 *a*) under Ammonium Carbonate.

Miles (1929) suggests that it is a useful control for slugs.

For other Copper Compounds see Paris Green p. 71, Arsenates p. 72, Borates p. 75 Fluorides p. 95.

Corrosive Sublimate (see Mercuric Chloride, p. 106).

Cotton Seed Oil.

This has principally been used as a medium for the application of various toxic agents in the control of the peach tree borer. See Snapp (1932) and Chandler (1939).

Creosote (see p. 37).

Cresol (see p. 35).

Crotonaldehyde ($CH_3CH : CH . CHO$).

Experiments in Air.

Lehman (1933) recorded the median lethal dose (50% kill) to the wireworm, *Pheletes californicus*, Mannh., as 0·74 mg./l. for a five-hour exposure, and 42·4 times as toxic as carbon disulphide.

Cryolite.

Cryolite is a complex naturally occurring compound of aluminium and sodium fluorides.

LEPIDOPTERA.

Crambidae.

Bohart (1940) obtained a good kill of the sod-webworms, *Crambus bonifatellus*, Hulst, and *C. sderryellus*, Klots, with applications of 5 lb./1,000 sq. ft. (24 gm./sq. m.), but the treatment severely burned the lawn.

COLEOPTERA.

Scarabaeidae.

Fleming (1942) obtained only low kills of *Popillia japonica*, Newm., grubs in pot experiments with rates of application up to 2,000 lb./ac. (224 gm./sq. m.) for an exposure of two weeks.

Cyanamide (see Calcium Cyanamide, p. 78).

Cyanides (see Calcium Cyanide p. 12, Sodium Cyanide p. 62; see also Potassium Cyanide p. 124, Hydrogen Cyanide p. 99, Methyl Cyanide p. 113, Mercury Cyanide p. 111).

Cymene ($CH_3 . C_6H_4 . CH(CH_3)_2$).

Liquid. S.G. 0·858–0·865. Occurs in the oils of thyme and eucalyptus.

Experiments in Air.

Tattersfield and Roberts (1920) para-: of uncertain toxicity. Fleming (1925) meta-: minimum lethal dose 90 mg./l. in air 1,000 gm./l. in water.

Derris.

Derris root or powder is the product derived from the roots of plants of the genus *Derris*. It is a well-known and widely used insecticide. The most important toxic principle in these roots is rotenone, though other substances more or less toxic also occur with it. Rotenone is now known to be present in other plants, e. g., *Lonchocarpus*. For a general survey of recent work on this subject see Shepard (1939). References to the use of the ground root, crude extracts and rotenone itself are for convenience included under the same heading.

LEPIDOPTERA.

Crambidae.

North and Thompson (1933) found a rotenone-containing substance applied as a spray to lawns at the rate of 1½ U.S. pints in 111 U.S. gals. water/1,000 sq. ft. (8 cc./sq. m.) had only a slight effect on *Crambus* sp. and not sufficient to be a satisfactory control. Bohart (1940) obtained kills approaching 100% of *C. bonifatellus*, Hulst, and *C. sperryellus*, Klots, on lawns in California with 1 U.S. gal./sq. yd. of a 1/400 dilution of a derris extract (11 cc./sq. m.).

COLEOPTERA.

Scarabaeidae.

Wolters (1934) found applications at the rate of 100–200 lb./ac. (11–22 gm./sq. m.) of derris powder to the top 2 ins. (5 cm.) of soil in boxes had no effect on the larvae of *Anomala orientalis*, Waterh. Fleming (1942) obtained nearly 80% kill of Japanese beetle larvae in pot experiments with applications at the high rate of 8,000 lb./ac. (900 gm./sq. m.) with derris alone, but when lime at 2,000 lb./ac. was added at the same time the kill dropped to about 24%. Similar low kills were also recorded even for chemically pure and commercial rotenone at the same rate (900 gm./sq. m.).

Curculionidae.

F. F. Smith (1932) stated that derris extract in varying concentrations was without effect on third- and fourth-instar larvae of the black vine weevil (*Otiorrhynchus sulcatus*, F.) and killed the primulas and cyclamens on which they were feeding. English and Graham (1938) only obtained low kills (10–23%) of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) when soil balls containing the larvae were immersed for 15 minutes in a pine-oil derris extract, derrisol, or cubé root.

DIPTERA.

Cecidomyiidae.

Mühlow and Sjöberg (1937) recorded no reduction in the infestation of wheat gall-midges (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) after the soil had been dusted with derris powder or sprayed with rotenone solution to control the hibernating larvae.

Bibionidae.

Edwards (1941) obtained 92–95% kill of larvae of the fever fly (*Dilophus febrilis*, L.) in lawns with the application of 1 gal./sq. yd. of a derris suspension containing 0·0054% rotenone (30 gm. rotenone/sq. m.). There was no injury to the herbage. 98–99% kills were obtained when a pyrethrum extract was added to the derris suspension to give a pyrethrin I content of 0·001%.

Psilidae.

By applying derris at 15 lb./ac.(1·7 gm./sq. m.) to carrot rows to control the carrot fly (*Psila rosae*, F.), Gorham (1934) reduced spring injury by the larva from 34% in the controls to 2·2% in the treated plots, and autumn injury from 51 to 31%. K. M. Smith and Wadsworth (1921) reported 95% carrots not attacked by the fly on plots treated with several applications of a mixture of soot and derris, whereas only 20% of the plants in the control plots were unattacked.

Anthomyiidae.

Brittain (1921) found the application of a mixture of equal parts of derris and clay applied to newly-set-out cabbages effectively protected them from attack by the root fly (*Hylemyia brassicae*, Bch.). Applied as a suspension at 1½ and 3 lb./100 gals. somewhat variable results were recorded. Derris did not appear to

have any effect on the fully grown larvae. He attributed unsatisfactory results in the following season (Brittain 1922) to using old stock. K. M. Smith and Wadsworth (1921) treated onions with a mixture of soot and derris powder to control attack by the onion fly (*Hylemyia antiqua*, Mg.) and obtained 60% onions on the treated plots free from attack. Soot alone only resulted in 16% unattacked plants.

SUMMARY.

Derris has not been successful in the control of Coleopterous larvae, but satisfactory results have been recorded with some other insects. It can hardly be considered as a suitable soil insecticide.

Diacetyl o-Phenylenediamine ($C_6H_4(NH.CO.CH_3)_2$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·66% by weight was toxic to *Popillia japonica*, Newm., larvae for a three-weeks' exposure.

2 : 4-Diamino Chlorbenzene ($C_6H_3(NH_2)_2Cl$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·33% by weight was toxic to *Popillia japonica*, Newm., larvae for a three-weeks' exposure.

Diamyl Phenol ($C_6H_3(C_5H_{11})_2OH$).

ISOPTERA.

Hockenyos (1939) found soil mixed with 0·5% by weight of this substance was toxic to termites.

p-Dibrombenzene ($C_6H_4Br_2$).

Crystalline.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) stated that this was not a very efficient insecticide for the peach tree borer (*Aegeria exitiosa*, Say), though he obtained kills of 96 and 85% with ½ and 1 oz. applications per tree.

Dibromnaphthalene ($C_{10}H_6Br_2$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight of this substance was toxic to *Popillia japonica*, Newm., larvae.

2 : 4-Dichloraniline ($NH_2C_6H_3Cl_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight was toxic to *Popillia japonica*, Newm., larvae for an exposure of two weeks.

o-Dichlorbenzene ($C_6H_4Cl_2$).

Liquid. S.G. 1·325 at 0° C. Often abbreviated to O.D.C.B.

This substance has generally only been used experimentally. It is inconvenient to handle and appears to be very toxic to plants. Out of 11 references dealing with its application to growing plants, six authors stated that more or less severe injury to the plants occurred. Mungomery (1932) found O.D.C.B. considerably reduced the yield of sugar-cane.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic.
Thalenhorst (1937) recorded 310 mg./l. for 72 hours as the minimum lethal dose for third-instar larvae of the cockchafer (*Melolontha hippocastani*, F.).

Experiments in Soil.

ISOPTERA.

Hockenyos (1939) found O.D.C.B. mixed with a standard soil in the proportion of 1 part to 200 was toxic to termites.

HEMIPTERA.

Coccidae.

Hosni and Shafik (1935) found O.D.C.B. at 2–10 gm./plant gave 97–100% kill of the mealybug, *Pseudococcus brevipes*, Ckll.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923*a*) recorded ½ fl. oz. per tree (18 gm.) as giving kills of peach tree borer (*Aegeria exitiosa*, Say) ranging from 62 to 84%. The treatment, however, resulted in considerable damage to the trees.

COLEOPTERA.

Scarabaeidae.

Jarvis (1930 *a* and *b*) obtained a complete kill of cane beetle grubs (*Dermolepida albohirtum*, Waterh.) with 7 cc. injections of O.D.C.B. per stool, but the plant was also killed. Chigarev (1932) recorded kills of 92 and 99% of Scarabaeid larvae in pine forests with O.D.C.B. applied in holes 20 ins. (50 cm.) apart with 40 gm. and 80 gm. doses, respectively (160 and 320 gm./sq. m.). Bennett (1940) applied emulsions of O.D.C.B. to small grass plots artificially infested with grubs of *Phyllopertha horticola*, L. Strengths of 0·48 and 1·28% killed 45 and 100% of the grubs respectively, but the weaker concentration resulted in slight, and the stronger in severe, injury to the grass.

Elateridae.

McDougall (1934) found O.D.C.B. applied at 600 lb./ac. (67 gm./sq. m.) close to sugar-cane sets ineffective for controlling *Lacon variabilis*, Cand., and also injurious to the plant.

Curculionidae.

Schwardt and Lincoln (1940), experimenting in the control of the alfalfa snout beetle (*Otiorrhynchus ligustici*, L.), found injections of 36 cc., 6 ins. (15 cm.) deep, at the rate of 3,737 lbs./ac. (420 gm./sq. m.), only killed 9·5% of the larvae within six days, but 79% were dead at the end of four weeks. Injury was caused to the lucerne.

Chrysomelidae.

Weigel and Doucette (1922) stated that O.D.C.B. was promising in the control of strawberry rootworm (*Paria canella*, F.) on roses, giving 52% kill at the highest tolerated dose of 3 cc. per plant.

DIPTERA.

Tipulidae.

Dawson (1932) gave details of an O.D.C.B. emulsion for the control of leather-jackets. It consists of O.D.C.B. 16 parts by volume; sodium oleate, 10% solution, 4 parts; Jeyes fluid, 4 parts, all diluted 1/400 and applied at 1 gal./sq. yd. (27 gm./sq. m.). This remedy does not kill them all but brings them to the surface, from which they can be removed. The treatment has been widely used and proved successful on golf greens and other lawns.

Bibionidae.

Edwards (1941), using this same emulsion, obtained 69·4–74·7% kill of the fever fly (*Dilophus febrilis*, L.) in lawns.

Psilidae.

K. M. Smith and Wadsworth (1921) used O.D.C.B. mixed with dry sand at 1 oz./sq. yd. (34 gm./sq. m.). This was ineffective in destroying or repelling the carrot fly (*Psila rosae*, F.), as only 20% clean carrots resulted.

SUMMARY.

The rates tested range between 30 and 400 gm./sq. m., but only occasionally have successful results been reported.

o-Dichlorbenzene applied in Solvents.

Mungomery (1931) obtained 83·7% kill of sugar-cane grubs (*Pseudholophylla furfuracea*, Burm.) with 4·8 cc. per stool of a solution of 1 part of O.D.C.B. in 2 parts of carbon disulphide. Severe injury to the plant resulted.

Mixtures of Dichlorbenzenes.

COLEOPTERA.

Elateridae.

Ladell (1938) used 560 lb./ac. (63 gm./sq. m.) of a proprietary mixture of dichlorbenzenes and obtained 69% reduction in the wireworm (*Agriotes* sp.) population in a field experiment compared with a reduction of 23% in the control. A similar mixture, but containing more O.D.C.B., at 800 lb./ac. (88 gm./sq. m.) gave a 62% reduction compared with 1% reduction in the controls.

Polychlorbenzenes.

These are mixtures containing various amounts of chlor- and dichlorbenzenes. They appear only to have been used in Russia, where they are known as polychlorides.

COLEOPTERA.

Scarabaeidae.

Kostenko (1930) obtained complete mortality of larvae of *Polyphylla fullo*, L., with polychlorbenzenes placed in holes 8 ins. (20 cm.) deep and 14 ins. (35 cm.) apart at 10 gm./hole (equivalent to 6⅓ cwt./ac. or 80 gm./sq. m.). The same result was obtained when the dose was 20 gm./hole, 28 ins. (70 cm.) apart (3⅙ cwt./ac. or 40 gm./sq. m.). Severe injury and death resulted to some seedlings when the soil

was treated at the time of planting, but soil treated the preceding year was safe. Golovyanko (1933 and 1935) gave details of the relative toxicity of various types of polychlorbenzenes to Scarabaeid larvae (mainly *P. fullo*, L., and *Melolontha hippocastani*, F.). The brownish yellow (66% O.D.C.B.) and dark polychlorbenzenes (39% O.D.C.B., 39% P.D.C.B.) gave good results (100% kill) at 500 lb./ac. (56 gm./sq. m.) applied in 1 oz. (28 gm.) doses in holes 28 ins. (70 cm.) apart and 8–12 ins. (20–30 cm.) deep. 93–96% kill was obtained with 0·2 oz. (6 gm.) doses 14 ins. (35 cm.) apart (364 lb./ac. or 40 gm./sq. m.). Pines 2–5 years old were not injured unless the substance was very close, but seedlings and young deciduous trees were injured.

The light brown and colourless polychlorbenzenes containing 66 and 52% chlorbenzenes were only effective at higher dosages, and the greenish polychlorbenzenes had no toxic effect. Krasnyanskiĭ (1937) also found vines were injured by soil treatment with polychlorbenzenes, although complete control of cockchafer larvae (*Melolontha* sp.) was obtained with 10 gm. doses 20 ins. (50 cm.) apart (40 gm./sq. m.).

p-Dichlorbenzene (see p. 41).

Dichlorethyl Ether (see p. 49).

Dichlorethylene (CHCl : CHCl).

Liquid.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (3100). Fleming (1925) minimum lethal dose 796 mg./l.

Diethyl Carbinol (see Amyl Alcohol, p. 69).

Dihydroxyanthraquinone (see Alizarin, p. 66).

2 : 4-Dichlor-6-Nitroaniline ($C_6H_2NH_2 . NO_2 . Cl_2$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight was toxic to *Popillia japonica*, Newm., larvae for an exposure of one week.

Dichlorpentane ($C_5H_{10}Cl_2$).

ISOPTERA.

Hockenyos (1939) found soil mixed with 0·1% by weight of a dichlorpentane distillate was toxic to termites.

LEPIDOPTERA.

Aegeriidae.

Chandler (1936 and 1939) obtained 70 and 95% kills of peach tree borers (*Aegeria exitiosa*, Say) with applications to the trees of 1 and 2 fl. oz., respectively.

2 : 4-Dichlorphenol ($Cl_2C_6H_3OH$).

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic (1·8).

Dimethyl Amine ($(CH_3)_2NH$).

Gas.

Experiments in Air.

Tattersfield and Roberts (1920) : moderately toxic (22).

Dimethyl Aniline ($C_6H_5N(CH_3)_2$).

Liquid. S.G. 0·958 at 20° C.

Tattersfield and Roberts (1920): highly toxic (6·6).

Dinitrobenzene ($C_6H_4(NO_2)_2$).

Crystalline.

Tattersfield and Roberts (1920) : non-toxic.
Fleming (1925) found the meta- form non-toxic at over 796 mg./l.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight of the meta- form toxic to *Popillia japonica*, Newm., larvae for an exposure of one week.

Dinitro o-Cyclohexyl Phenol ($C_6H_{11} . C_6H_2(OH)(NO_2)_2$).

LEPIDOPTERA.

Crambidae.

Bohart (1940) obtained approximately 70% kill of the webworms (*Crambus bonifatellus*, Hulst, and *C. sperryellus*, Klots) with 1/1,000 dilution at 1 U.S. gal./sq. yd. (5 cc.)/sq. m.).

1 : 5-Dinitronaphthalene ($C_{10}H_6(NO_2)_2$).

Crystalline.

Experiments in Air.

Fleming (1925) : non-toxic at 796 mg./l.

2 : 4-Dinitrophenol ($OHC_6H_3(NO_2)_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight was toxic to *Popillia japonica*, Newm., larvae for an exposure of one week.

Dinitrotoluene ($CH_3 . C_6H_3(NO_2)_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight was toxic to *Popillia japonica*, Newm., larvae for an exposure of two weeks.

Diphenyl ($C_6H_5 . C_6H_5$).

Crystalline.

Experiments in Air.

Fleming (1925) . non-toxic at over 796 mg./l.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight was toxic to *Popillia japonica*, Newm., larvae for an exposure of one week.

Diphenylamine ($(C_6H_5)_2NH$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): non-toxic.

Experiments in Soil.

ISOPTERA.

M. W. Smith (1939) found sand mixed with 0·01% by weight of diphenylamine was toxic to termites and remained effective for five months.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% by weight was toxic to *Popillia japonica*, Newm., larvae for an exposure of two weeks.

Epichlorhydrin $\left(O\!\left\langle \begin{array}{l} CH_2 \\ | \\ CH \, . \, CH_2Cl \end{array} \right. \right)$.

Liquid. S.G. 1·203 at 0° C.

Experiments in Air.

Lehman (1933) recorded 0·79 mg./l. for a five-hour exposure as the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh.; it was 39·8 times as toxic as carbon disulphide.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Bell (1935) reported that epichlorhydrin was less toxic than carbon disulphide to the sugar-cane grub, *Dermolepida albohirtum*, Waterh.

Ether ($C_2H_5 \, . \, O \, . \, C_2H_5$).

Liquid. S.G. 0·719.

Experiments in Air.

Fleming (1925): minimum lethal dose 796 mg./l.

Ethyl Alcohol (C_2H_5OH).

Liquid. S.G. 0·789 at 20° C.

COLEOPTERA.

Elateridae.

Wilson (1940) tested 96% alcohol as a check in experiments in which it was used as a solvent for other substances; applied in holes 3 ins. (7·5 cm.) deep and 6 ins. (15 cm.) apart at 3 cc. per hole (100 gm./sq. m.), it had no effect on wireworms (*Melanotus communis*, Gylh.) in seed beds.

Ethylamine ($C_2H_5NH_2$).

Liquid. S.G. 0·689.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (22).

Ethyl Formate ($H.COOC_2H_5$).

Liquid. S.G. 0·917.

Experiments in Air.

Lehman (1933) recorded 16·65 mg./l. as the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh., for a five-hour exposure; it was 1·9 times as toxic as carbon disulphide. Fleming (1928) found it more toxic than carbon disulphide to *Popillia japonica*, Newm., larvae.

Ethylene Chlorhydrin ($CH_2Cl.CH_2OH$).

Liquid. S.G. 1·24 at 8° C.

Experiments in Air.

Lehman (1933) recorded 0·24 mg./l. as the median lethal dose (50% kill) for a five-hour exposure for the wireworm, *Pheletes californicus*, Mannh.; it was 131·9 times as toxic as carbon disulphide.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Bell (1935) found it less toxic than carbon disulphide to the sugar-cane grub, *Dermolepida albohirtum*, Waterh.

Ethylene Dichloride ($CH_2Cl.CH_2Cl$).

Liquid. S.G. 1·257 at 20° C.

Experiments in Air.

Lehman (1933) recorded 24·48 mg./l. for a five-hour exposure as the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh.; it was 1·3 times as toxic as carbon disulphide.

Experiments in Soil.

THYSANOPTERA.

Richardson and Nelson (1933) found a 1/750 emulsion applied to gladiolus corms the day after setting them out, at the rate of 1 U.S. gal. per 50 corms, was ineffective for the control of gladiolus thrips (*Taeniothrips gladioli*, Mlt. & Stwn.).

HEMIPTERA.

Aphidae.

Chandler (1940 *b*) found 10 and 20% emulsions applied at ¼ U.S. pint (12–14 cc.) per tree ineffective for the control of the black peach aphis (*Anuraphis persicae-niger*, Smith) on peach trees.

LEPIDOPTERA.

Aegeriidae.

Aegeria exitiosa, Say (Peach Tree Borer).

Snapp and Thomson (1934*a*) obtained promising results in the control of the borer with doses of 1–2 fl. oz. (30–60 cc.) per tree. Later (1936) they found emulsions were more effective, and used an emulsion consisting of 9 parts by volume of ethylene dichloride and 1 part of potash fish-oil soap containing about 70% water. Doses of $\frac{1}{8}$–$\frac{1}{2}$ U.S. pint of 5–20% dilution of the stock emulsion per tree were recommended according to its age (Snapp and Thomson, 1936; Snapp, 1938; Chandler, 1939). Less damage was caused to young trees, especially in the warmer areas, than by p-dichlorbenzene, and the treatment was also slightly cheaper and could be applied more expeditiously as a spray to the base of the tree (Snapp, 1939*b*). According to this author, mounding the bases of the trees, as was normally practised for paradichlorbenzene, was also unnecessary, but Chandler (1940*a*) advised mounding for autumn treatments. When the treatment was adopted commercially, it caused injury to the trees in certain districts. This damage was investigated by Worthley and Steiner (1942), who stated that it appeared to be associated with certain soil and seasonal conditions, but they were unable to account for it entirely.

A. opalescens, Edw. (Prune Root Borer).

Jones (1940*b*) obtained 100% kill of the prune root borer with $\frac{1}{2}$ U.S. pint of a 25% emulsion poured around the base of the trunk and mounded. Sprayed on, it was not quite so effective, giving 79% kill when mounded and 61% not mounded.

COLEOPTERA.

Scarabaeidae.

Bell (1935) found it less effective than carbon disulphide for the control of *Dermolepida albohirtum*, Waterh., grubs attacking sugar-cane.

The Addition of other Substances to Ethylene Dichloride.

Walker and Anderson (1937) applied a mixture of 75% ethylene dichloride and 25% carbon tetrachloride to control pavement ants (*Tetramorium caespitum*, L.) attacking egg-plants, but the treatment resulted in the death of the plant.

Ethylene Oxide (C_2H_4O).

Gas or liquid. S.G. 0·897 at 0° C. Boiling point 14° C.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Osburn (1931) obtained 100% kill of *Popillia japonica*, Newm., larvae in soil balls of 6 ins. (15 cm.) diameter with 2 lb. ethylene oxide per 1,000 cu. ft. of air for an exposure of three hours, or 7½ lb./1,000 cu. ft. for two hours. Soil balls 14 ins. (35 cm.) in diameter required 10 lb./1,000 cu. ft. for three hours.

Ferric and Ferrous Salts (see Arsenates, p. 72).

Fish Oil.

Experiments in Soil.

COLEOPTERA.

Elateridae.

Zappe (1922) tested a fish-oil emulsion (4 oz. soap, 4 oz. fish oil, 1 U.S. quart water) as a remedy for wireworms attacking tobacco seedlings, but found it ineffective.

Fluorides.

Fluorides are the salts of hydrofluoric acid. For convenience they are dealt with together. Both these and the fluosilicates have proved promising as stomach insecticides.

Experiments in Water.

Leach and Thomson (1921) found 1–10% solutions of potassium fluoride useless as dips for *Popillia japonica*, Newm., larvae.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Leefmans (1915) only recorded two dead cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.) out of eight in soil watered with a 1/10% solution of sodium fluoride. Lipp (1929) obtained unsuccessful results in the control of *Popillia japonica*, Newm., larvae in pot experiments using the fluorides of aluminium, barium, calcium, copper, lead and zinc-ammonium at the rate of 1,500 lb./ac. (168 gm./sq. m.). Fleming (1942) also tested the toxicity of the fluorides of aluminium, barium, calcium, copper, lead, magnesium, strontium and zinc to *Popillia japonica*, Newm., larvae in pot experiments at rates up to 2,000 lb./ac. (224 gm./sq. m.) and found them all non-toxic (survival rates about 70–90%). They were also not detrimental to plants. (See also Cryolite, p. 85).

Fluosilicates (Silicofluorides).

Shepard (1939) gives some chemical and physical details of these compounds.

Experiments in Soil.

ISOPTERA.

Kofoid (1934) reported that ground treated with 5 and 10% solutions of magnesium fluosilicate at 10 U.S. gals. per 100 sq. ft. (204 and 408 gm./sq. m.) remained free from termites for over a year, whereas the surrounding untreated ground was infested.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) tested the toxicity of barium, calcium and sodium fluosilicates to larvae of the Japanese beetle in pot experiments at 1,500 lb./ac. (168 gm./sq. m.). The barium and sodium salts were effective and grasses grew normally in the treated plots. Fleming (1942) in similar tests found freshly applied sodium fluosilicate to be even more effective than acid lead arsenate; the fluosilicates of barium and potassium were about the same as lead arsenate, but that of magnesium was less. Calcium fluosilicate was non-toxic up to 2,000 lb./ac. (224 gm./sq. m.). None of them was of any value after six months.

Metzger (1933) mixed soil in a glasshouse with barium fluosilicate to a depth of 6 ins. (15 cm.) at the rate of 3,000 lb./ac. (336 gm./sq. m.). In the following winter only two Japanese beetles emerged from the plot thus treated out of 500 third-instar larvae previously placed there, compared with 214 emerging from the control plot. Nichol (1935) obtained 85% kill of larvae of the fig beetle (*Cotinis texana*, Casey) by applying 1½ lb. sodium fluosilicate to a plot 20 ft. square (18 gm./sq. m.) in one experiment, but the substance was not reliable. Neiswander (1936) obtained only 32% kill of the white grub, *Lachnosterna hirticula*, Knoch, with a proprietary chemical containing 80% barium fluosilicate applied at 5 lb./1,000 sq. ft. (25 gm./sq. m.), whereas lead arsenate applied at the same rate gave 77% kill.

Elateridae.

Headlee (1927) recorded wireworms surviving in soil containing 1% of calciu fluosilicate. McDougall (1934) found sodium fluosilicate ineffective as a contr measure for the Queensland sugar-cane wireworm, *Lacon variabilis*, Cand.

DIPTERA.

Chironomidae ?

Fulton (1933) was unable to control midge larvae in tobacco seed beds wit applications of barium fluosilicate.

Psilidae.

Gorham (1934) reduced spring injury to carrots by the carrot fly, *Psila rosae*, F., from 34% in controls to 4% in plots treated wtih sodium fluosilicate at 400 lb./ac. (45 gm./sq. m.). Autumn injury was reduced from 51% to 25%.

Anthomyiidae.

In an anonymous publication (New York, 1928) it was found that an aqueous solution of sodium fluosilicate at 1/250 was one of the best substances out of many tested for the control of the cabbage root fly (*Hylemyia brassicae*, Bch.).

Formaldehyde (H . CHO).

Colourless gas, normally used dissolved in water as 40% solution and containing about 15% of methyl alcohol. This mixture is known as formalin. It has proved particularly useful as a soil fungicide, but appears to be of very little value as an insecticide. As a sterilising agent for glasshouse soil, 1 gallon of 40% formaldehyde diluted with 49 gallons of water is applied to 10–18 sq. yd. (545–305 gm./sq. m.) (Bewley, 1935).

Experiments in Air.

Fleming (1925): minimum lethal dose 44 mg./l.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Blake and Connors (1914) obtained 50% kill of white grubs (*Lachnosterna* sp.) in glasshouse soils by saturating the soil with a 1/75 solution. A second application of 1/50 killed more. Leach and Johnson (1925) watered the roots of perennial plants infested with Japanese beetle larvae with a 5% solution; the grubs were unaffected but the plants were killed; grubs in soil balls were killed when these were dipped in the solution for two hours. Fleming (1928) stated that the gas did not penetrate the soil at all, as it was absorbed by the surface layers.

Elateridae.

Russell (1920) reported that formalin was of no value for controlling wireworms (*Agriotes* sp.) in the soil.

Curculionidae.

English and Graham (1938) also found a 37% solution of formalin ineffective for the control of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) when soil balls containing this insect were immersed in the solution for 15 minutes.

Furfural(dehyde) (C_4H_3O . CHO).

Liquid. S.G. 1·159 at 20° C.

Experiments in Air.

Fleming (1925) : minimum lethal dose 44 mg./l.

Experiments in Soil.

According to Fleming (1928), furfural does not penetrate the surface of the soil and is probably absorbed by the surface water.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained negative results in the control of the peach-tree borer (*Aegeria exitiosa,* Say) with ½-oz. applications per tree.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) found 3% solutions ineffective for treating soil around the roots of perennial plants infested with Japanese beetle larvae.

Gas Lime (see also Calcium Sulphide).

Lime was formerly used for removing hydrogen sulphide and carbon dioxide from the crude coal gas as it issued from retorts. As it became saturated, the lime was replaced and the waste product was known as gas lime or " blue billy ". When fresh it had an unpleasant smell largely due to the calcium sulphide (p. 80) it contained. Voelcker (1880) gave the following analysis of a sample kept long enough to be used as a fertiliser and dried at 212° F. When fresh, the amount of water varied between 30 and 40%.

	%
Water of combination and organic matter	7·24
Oxides of iron and alumina with traces of phosphoric acid	2·49
Sulphate of lime	4·64
Sulphite of lime..................................	15·19
Carbonate of lime	49·40
Caustic lime	18·23
Magnesia and alkalis	2·53
Insoluble siliceous matter	0·28

In this sample the calcium sulphide has already been oxidised to the sulphite and sulphate. For use as lime or a fertiliser Voelcker recommended applications of about 2 tons per acre. Ormerod (1890) also recommends it at this rate as an insecticide for various soil pests.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Theobald (1927) reported that it was unsuccessful in controlling cockchafer larvae (*Melolontha melolontha,* L.) on grassland.

Elateridae.

Comstock and Slingerland (1892) found it was effective against wireworms if used fresh in large quantities, but its usefulness soon disappeared.

Gas Liquor (see Ammonia, p. 67).

Gasoline (see Petroleum Oils, p. 121).

Guano.

A phosphatic fertiliser,

COLEOPTERA.

Chrysomelidae.

Feytaud (1938) found applications of 1,200 kg./ha. (120 gm./sq. m.) caused appreciable reductions of Colorado beetle larvae (*Leptinotarsa decemlineata*, Say) in pot experiments.

Hellebore.

Commercial powdered hellebore is made chiefly from the white hellebore (*Veratrum album*, Liliaceae) which grows in the mountains of central and southern Europe. The parts of the plant used are the rhizomes and rootlets (Shepard 1939). As a general insecticide it is used as a dust or as a decoction. It deteriorates very rapidly when exposed to the air and should always be used fresh.

Experiments in Soil.

LEPIDOPTERA.

Noctuidae.

Hawley (1918) found one or two handfuls of a mixture of one part of hellebore and four parts of lime per hill had no effect on the hop borer (*Hydroecia immanis*, Gn.). One U.S. pint of a decoction of 5 oz. hellebore in 2½ U.S. gals. water was equally inefficient.

COLEOPTERA.

Scarabaeidae.

Jarvis (1916) obtained negative results in the control of the sugar-cane grub (*Dermolepida albohirtum*, Waterh.) with a decoction of 1 lb. in 12 gals. water, though the failure might have been due to the use of old stock. Fleming (1942) reported only small kills (up to about 35%) of *Popillia japonica*, Newm., larvae in pot experiments with applications up to 8000 lb./ac. (900 gm./sq. m).

DIPTERA.

Anthomyiidae.

Slingerland (1894) found decoctions of 1 oz. hellebore in 1 U.S. gal. water applied to cabbage plants were ineffective in controlling root maggots (*Hylemyia brassicae*, Bch.). Smith and Dickerson (1907) suggested the application of 4–6 fl. oz. per plant of a 1/30 dilution of 2 oz. hellebore in 1 U.S. gal. of soapy water for the control of cabbage and onion maggots (*H. brassicae*, Bch., and *H. antiqua*, Mg.). MacDougall (1913) recommended a rather stronger dose of ⅓ U.S. pint per plant of 2 oz. hellebore per U.S. gal. Eyer (1922) found it useless as a remedy for onion maggot.

Heptane ($CH_3(CH_2)_5CH_3$).

Liquid. S.G. 0·689.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (800).

Hexachlorethane (Carbon Hexachloride) ($CCl_3.CCl_3$).

Crystalline.

Experiments in Air.

Fleming (1925): minimum lethal dose in air 124 mg./l.; in water 157 mg./l.

Thalenhorst (1937) recorded the minimum lethal dose to cockchafer larvae (*Melolontha hippocastani*, F.) as 166 mg./l. for an exposure of 96 hours.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Thalenhorst (1937) was unable to kill caged cockchafer larvae buried 25 cm. deep and 14–25 cm. from 5 gm. injections.

DIPTERA.

Trypetidae.

Fairly successful results in the destruction of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) were obtained by Thiem (1934) with 10 gm. hexachlorethane applied to pots 180 sq. cm. in area (555 gm./sq. m.).

Hexane ($CH_3(CH_2)_4CH_3$).

Liquid. S.G. 0·660 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (3,000).

Hydrogen Cyanide (Hydrocyanic Acid) (HCN).

Liquid, boiling at 26° C. S.G. 0·682 at 25° C.

Pure hydrogen cyanide has been, and is only likely to be, used experimentally as a means of studying its effect when given off in the soil from sodium or calcium cyanide. A general account of its use as a soil insecticide is given by De Ong (1917). He and other workers stress its ineffectiveness in wet soil.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (20). Fleming (1928) reported that it was more toxic in air and water to larvae of *Popillia japonica*, Newm., than carbon disulphide.

Experiments in Soil.

DERMAPTERA.

Mackie (1935) reported that earwigs (*Forficula auricularia*, L.) 2 ins. (5 cm.) deep in soil exposed to hydrocyanic acid gas were killed; some of the plants were also killed.

COLEOPTERA.

Scarabaeidae.

Sawa (1935) reported that hydrogen cyanide was as effective as chlorpicrin in destroying larvae of *Anomala rufocuprea*, Motsch., in the upper layers of the soil in laboratory experiments, but less effective in the deeper layers.

Elateridae.

Stone and Campbell (1933) also found its penetrating properties poor compared with chlorpicrin in the control of wireworms (*Pheletes californicus*, Mannh.); 20–25 cc. of liquid cyanide in 5–6 U.S. gals. water/sq. yd. (15–18 gm./sq. m.) gave 50–70% kill to a depth of 4 ins. (10 cm.), and even lower kills below this depth.

MISCELLANEOUS.

Sasscer and Sanford (1918) found the treatment of soil balls containing various species of soil pests with hydrocyanic acid was invariably ineffective if the soil was wet; in dryer soils the treatment was most effective under vacuum conditions, but the concentration necessary to kill the larvae also killed plants.

Hydroquinone (Quinol) ($C_6H_4(OH)_2$).

Crystalline.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·03% of hydroquinone was toxic to larvae of *Popillia japonica*, Newm., for an exposure of one week.

ISOPODA.

Speyer and Owen (1924) found one part of hydroquinone to 227 parts of soil gave 100% kill of the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) within 24 hours, and remained effective for 3–5 days.

Iodobenzene (C_6H_5I).

Liquid.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (50).

Iodoform (CHI_3).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): non-toxic.

Kainit.

Kainit is a complex potassic fertiliser; the original deposits in Germany have been practically exhausted, but the name is still retained for the lowest grades of potassic fertiliser. Its composition is thus not constant, varying with the mine and the method of working. It is so mined that it contains the equivalent of 14–16% potassium chloride (Russell 1939).

Experiments in Soil.

LEPIDOPTERA.

Noctuidae.

According to Herold (1920), kainit applied at about 63 gm./sq. m. had a repellent effect on cutworms (*Agrotis segetum*, Schiff.), so that 61% of the population were found in a ditch surrounding the treated plot.

COLEOPTERA.

Scarabaeidae.

Theobald (1927) at 3–6 cwt./ac. (38–76 gm./sq. m.), and Hengl (1935) at 800 kg./ha. (80 gm./sq. m.) found kainit unsuccessful for the control of cockchafer larvae (*Melolontha melolontha*, L.). Kaysing (1934), however, obtained 100% kill with 12 dz./ha. (120 gm./sq.m.). The kainit was distributed on the surface and carried into the soil by rain, so that two or three months elapsed before it was fully effective. According to Subklew (1936 *a* and *b*) Melolonthid larvae are highly resistant to changes in soil solution, and the amount of kainit or other potassic salts necessary to bring about effective control would be too expensive and too dangerous to vegetation. The same conclusion was reached by Schwertfeger (1936).

Elateridae.

Comstock and Slingerland (1892) at 4–9 U.S. tons/ac. (900–2,000 gm./sq. m.), Webster (1899) at 2,400 lb./ac. (270 gm./sq. m.), and Ingram *et al.* (1939) at 300 lb./ac. (34 gm./sq. m.), found it to be ineffective against wireworms. Weigand (1924) recommended finely ground kainit dug into the soil in wet weather at the rate of 600 kg./ha. (60 gm./sq. m.) to control wireworms in sugar-beet fields. Malenotti (1927) recorded improved results over the controls by applying it to maize at 10 gm per plant and using 4 quintals/ha. (40 gm./sq. m.). Hawkins (1936) obtained promising results in preliminary experiments at 450 lb./ac. (50 gm./sq. m.), but was unable to repeat the results successfully. He suggested that the inconsistency might be due to variation in the composition of the substance.

Subklew (1938) lists 28 papers in which the authors recommend kainit for wireworm control and 13 papers in which the authors had found it unsuccessful. Langenbuch and Subklew have both attempted to trace the toxic principle involved. Langenbuch (1933) suggested that its toxicity was due to upsetting the water-balance of the insect, and he found that wireworms were more resistant in winter than in summer. Subklew (1934) investigated the relative toxicity of the various ions concerned, finding potassium to be the most toxic of the cations. He stated that a 2 % solution was harmful to wireworms (*Agriotes* sp.), but to produce this strength in a saturated soil it would be necessary to apply 30–40 times the amounts of kainit normally used in practice. As this concentration was much higher than that found to be necessary by Langenbuch, the two workers carried out joint experiments (Langenbuch and Subklew 1934) which showed that the resistance of the larvae varied according to their place of origin. Subklew later (1935) confirmed this, stating that wireworms susceptible to potassic chloride generally came from the loams and sandy soils of middle, north and south-east Germany, and the resistant ones from bog and moorland soils. Thus kainit is only likely to be of value in controlling wireworms on the former types of soil, and will only afford direct control when the potassium chloride content is the highest possible (Subklew 1936 *c*).

DIPTERA.

Tipulidae.

Thompson (1926) found no dead leatherjackets (*Tipula* sp.) and numerous live ones on land treated with kainit at 4 cwt./ac. (50 gm./sq. m.).

Cecidomyiidae.

Klee and Rademacher (1935) obtained 52–66% control of wheat gall-midge larvae (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) by applying kainit to the soil after autumn ploughing or in the spring at 6–14 dz./ha. (60–140 gm./sq. m.). Mühlow (1936) only obtained 33% kill of these larvae using 800 kg./ha. (80 gm./sq. m.).

SUMMARY.

The tested rates range from 30–2,000 gm./sq. m., and only five successful results have been reported out of the fourteen experiments cited.

Kerosene (Paraffin, Burning Oil).

Liquid. S.G. approximately 0·8.

Kerosene is a mixture of paraffins with a boiling range of about 150–300° C. It is mainly derived from petroleum oil, and for a very long time has been used as a contact insecticide and as a soil fumigant. It is harmful to vegetation, but this effect is not very permanent. It is usually applied watered on as an emulsion or injected into the soil more or less pure. According to Thiem and Kalandadze (1931), it has good spreading properties in the soil, which are somewhat lessened when it is used as an emulsion. Leach (1918) found that practically all the kerosene in an emulsion was retained by the top 4 ins. (10 cm.) of soil.

Experiments in Soil.

ISOPTERA.

Pomeroy (1927) recommended a stock soap-kerosene emulsion consisting of 4 gals. kerosene, 1 lb. soap, and 2 gals. water, diluted to 1/9 and applied at 1,350 gals./ac. (90 gm./sq. m.) to kill termites infesting the soil after the destruction of their nests.

HEMIPTERA.

Aphidae.

Cory (1915), who used 4 U.S. gals. of a 10% emulsion per tree, and Leach (1918) tested kerosene emulsions for the control of woolly apple aphis (*Eriosoma lanigerum*, Hsm.), and both reported severe injury to apple trees. Leach stated also that it did not kill Aphids at lower levels. Marcovitch (1934) also found it worthless. Davidson (1917), however, found 10–20% emulsions quite effective for the control of pear woolly aphis (*E. pyricola*, Bak. & Dav.), although 1 U.S. gal. per tree was not sufficient to reach the deepest roots, and there was some scorching of surface roots.

LEPIDOPTERA.

Crambidae.

Noble (1932) reported favourably on a stock emulsion consisting of ½ U.S. gal. kerosene stirred into 1 U.S. gal. of boiling water with 1 lb. soap, diluted to 1/50 and applied at 1 U.S. gal./sq. yd. (24 gm./sq. m.) for the control of sod webworms in turf. Jewett (1939) also obtained high kills (94–95%) at a much higher rate with a 1/10 dilution of a stock emulsion containing 2 U.S. gals. kerosene, 1 U.S. gal. water and ½ lb. hard soap, applied at 1 U.S. gal./10 sq. ft. (217 gm./sq. m.). North and Thompson (1933) and Stone and Elmore (1937) found applications of about the same strength as Noble's ineffective.

COLEOPTERA.

Scarabaeidae.

Alwood (1888) found a 1/30 kerosene emulsion, liberally applied, quite successful for the control of white grubs (*Cotinis nitida*, L.). Davis (1920 *a*), using an 8% emulsion, obtained 80% kill of *Cotinis* grubs in golf greens applying 1 U.S. gal./6–8 sq. ft. (325–490 gm./sq. m.). He also obtained effective control of Japanese beetle larvae (*Popillia japonica*, Newm.) applying 1 U.S. gal./4 sq. ft. (650 gm./sq. m.). Nichol (1935), however, found 1 U.S. gal. of an 8% emulsion applied to 400 sq. ins. (940 gm./sq. m.) was useless for the control of the fig beetle (*Cotinis texana*, Casey).

Elateridae.

Comstock and Slingerland (1892) found 1 part of kerosene emulsion diluted with 20 parts of water and applied at about 2 U.S. gals./sq. yd. (450 cc. emulsion/sq. m.) was ineffective for the control of wireworms. McDougall (1934) also reported that a 25% emulsion applied close to sugar-cane sets at planting time at 1 l./11 yds. of row (20 cc./m.) was useless for the control of the wireworm, *Lacon variabilis*, Cand.

Curculionidae.

F. F. Smith (1932) stated that kerosene emulsions in varying concentrations killed primulas and cyclamens without harming third-instar larvae of the vine weevil, *Otiorrhynchus sulcatus*, F. In an anonymous publication (New York 1937) it is said that infestation of the apple curculio (*Tachypterellus quadrigibbus*, Say) was reduced by 79 and 91% compared with the previous year by spraying the turf below the trees with a 25% emulsion.

DIPTERA.

Cecidomyiidae.

Mühlow and Sjöberg (1937) found that kerosene applied to the soil at 2 gals./100 sq. yds. (9 gm./sq. m.) reduced the percentage of wheat ears infested by gall-midges (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) from 16 to 6, but caused injury to the plants.

Psilidae.

Ironside (1921) mixed kerosene with wood ashes (1 qt. per bushel) and spread the mixture over a carrot bed after previously watering it well. The mixture was hoed in and a few days later all the carrot fly, *Psila rosae*, F., grubs around the roots were dead. Two bushels covered 300 sq. yds. (7 gm./sq. m.).

Anthomyiidae.

Hylemyia brassicae, Bch. (Cabbage Root Maggot).

More or less successful early experiments in the control of this pest by kerosene are described by Cook (1886), who used a 10% emulsion applied at one tablespoonful per plant every few days; by J. B. Smith (1890), who used a stock emulsion consisting of 2 parts of kerosene to 1 part of water diluted to 1/12 or 1/15, and by Slingerland (1894), who used a similar mixture. Krasnyuk (1931) found no significant difference between plants treated with kerosene emulsion and the controls.

H. antiqua, Mg. (Onion Fly).

K. M. Smith (1923) obtained a considerably greater yield of onions on plots treated with a 1/20 emulsion compared with the control plots.

Trypetidae.

Hammer (1934) obtained a 96% kill of pupae of *Rhagoletis pomonella*, Walsh, in artificially infested plots sprayed with a 10% emulsion, and 100% kill with 25 and 50% emulsions.

The Addition of other Substances to Kerosene.

Nicotine. Weigel and Doucette (1922) obtained promising but somewhat variable results in the control of the strawberry root worm (*Paria canella*, F.) attacking roses with a 1/16 to 1/32 dilution of a kerosene-nicotine oleate emulsion.

Creoline. Corbett (1926) recommended a 1% dilution of an emulsion consisting of ¾ lb. soap, ½ gal. boiling water and 1 gal. kerosene, and ¾ gal. creoline churned in, to control the red ant (*Solenopsis geminata*, F.) attacking tobacco seedlings.

Carbon Disulphide. Leefmans (1915) stated that the addition of kerosene to carbon disulphide at various rates decreased the effectiveness of the latter in the control of cassava grubs, *Leucopholis rorida*, F., and *Lepidiota stigma*, F. (Scarabaeidae). Printz (1926) obtained complete control of *Phylloxera* with a mixture of equal parts of kerosene and carbon disulphide applied at 2 oz./sq. yd. (approximately 30 cc. of each/sq. m.).

p.-Dichlorbenzene (see p. 49). Mühlow and Sjöberg (1937); Hammer (1934).

Naphthalene (see p. 61). Hammer (1934).

Pyrethrum (see p. 128). Mühlow and Sjöberg (1937).

SUMMARY.

The rates tested range from 9–940 gm./sq. m.

Lead Salts (see Lead Arsenate, p. 51, Borates, p. 75, Fluorides, p. 95).

Lime.

For agricultural purposes lime is used in several forms, the principal of which are calcium oxide or quicklime, calcium hydroxide or slaked lime, and calcium carbonate or limestone. When it has been advocated for insecticidal purposes the type is not always stated, but usually the more caustic quicklime is intended. For convenience, references to all forms are put under one heading. Lime is also frequently used as a diluent to bulk small quantities of other substances to facilitate their distribution. Hutchinson (1913) has studied the effect of partial sterilisation caused by the application of lime to soil.

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Peterson (1922) stated that hydrated lime applied to peach trees reduced but did not prevent attack by peach-tree borer (*Aegeria exitiosa*, Say). Later (1923 *a*) he reported that it was quite useless for this purpose.

COLEOPTERA.

Scarabaeidae.

Decoppet (1920) stated that according to Dr. Schneider-Orelli of Zurich, powdered quicklime applied at 165 gm./sq. m. was ineffective for the control of cockchafer larvae (*Melolontha melolontha*, L.). Metzger (1933) obtained a total of 49 Japanese beetles (*Popillia japonica*, Newm.) emerging from soil in a greenhouse treated with 3,000 lbs. hydrated lime/ac. (336 gm./sq. m.), compared with 214 emerging from a control plot. Both plots had been artificially infested with 500 third-instar larvae. Fleming (1942) found hydrated lime and limestone had little effect on these larvae at rates up to 8,000 lb./ac. (896 gm./sq.m.).

Elateridae.

Comstock and Slingerland (1892) found that both slaked and unslaked lime were without effect on wireworms. McDougall (1934) also found slaked lime at 1,000 and 2,000 lb./ac. (112 and 224 gm./sq. m.) applied in the drills with sugar-cane sets or incorporated into the soil surrounding the sets was ineffective for controlling the wireworm, *Lacon variabilis*, Cand. Neither Hawkins (1936), using quicklime at 1,000 lb./ac. (112 gm./sq. m.), nor Ladell (1938), using hydrated lime at 34 cwt./ac. (430 gm./sq. m.), obtained any significant reduction in the control of *Agriotes* sp. in field experiments. Herrmann (1919), however, recommended unslaked lime worked into dry soil to control wireworms, which would then be killed when the lime was slaked by rain.

DIPTERA.

Cecidomyiidae.

Mühlow (1936) obtained a 59% reduction of wheat gall-midge larvae (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) in a field experiment on soil treated with 1,800 lb./ac. (200 gm./sq. m.).

Chironomidae.

McCarthy (1922) was able to destroy a large number of larvae of the seed-bean midge, *Smittia macleayi*, Skuse, in New South Wales by working lime into the surface before planting.

Trypetidae.

Rhagoletis cerasi, L. (Cherry Fruit-fly).

To sterilise soil infested with the pupae, Mayné (1932) recommended quicklime mixed with the soil in the proportion of 1 to 4 and the mixture wetted to slake the lime. The heat created by the slaking was sufficient to destroy the pupae. Wiesmann (1933) found quicklime at 300 gm./sq. m. quite ineffective for the control of the pupae.

The Addition of Lime to other Substances.

Sulphur (see p. 134), Michelbacher (1932); *Mercuric Chloride* (see p. 107), Peterson (1923 *a*); *Hellebore* (see p. 98), Hawley (1918).

SUMMARY.

Range, 112–896 gm./sq. m. It would seem that the belief frequently met with amongst farmers that lime is of value as a soil insecticide has no foundation.

Lime Sulphur and Lime Sulphur Residues.

Lime sulphur, a well-known fungicide, is made by boiling milk of lime with sulphur, and contains in solution varying amounts of polysulphides and finely divided sulphur. Its chemical structure is discussed by Martin (1936). By-products from its manufacture containing sulphur compounds and other substances have also been suggested as insecticides, and are considered here.

Experiments in Soil.

COLEOPTERA.

Elateridae.

Peterson (1917) obtained no control of wireworms in pot experiments with applications of lime sulphur up to rates corresponding to 500 U.S. gals./ac. (470 cc./sq. m.). Gough (unpublished) obtained no kill of wireworms (*Agriotes* sp.) in pot experiments with lime sulphur residues at rates up to 4 tons per acre (1000 gm./sq. m.) in the form of an untreated sludge and the same product dried and ground.

Curculionidae.

English and Graham (1937) only obtained low kills of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) in soil balls immersed in lime sulphur solution, alone and containing nicotine sulphate.

DIPTERA.

Cecidomyiidae.

Tanabe and Sekiya (1931) recommended lime sulphur solution for the control of larvae of *Diplosis mori*, Yokoy., in the soil.

Anthomyiidae.

Brittain and Lowry (1916) reduced the infestation of cabbage root fly (*Hylemyia brassicae*, Bch.) from 23% in the controls to 11% on plants treated with 3 fl. oz. each of a lime sulphur sludge diluted with five times its weight of water. Brittain (1920) found a mixture of dry lime sulphur (20%) and clay (80%) applied to cabbage plots at 700 lb./ac. (15 gm. L.S./sq. m.) was ineffective as a control for the maggots. Mixtures with tobacco dust and sodium arsenite also gave negative results.

Magnesium Salts.

Experiments in Soil.

COLEOPTERA.

Elateridae.

Hawkins (1936) found mixtures of 1 part of magnesium chloride or 1 part of magnesium sulphate in 35 and 14 parts of soil respectively were toxic to the wireworm, *Agriotes mancus*, Say.

DIPTERA.

Anthomyiidae.

Edwards (1935) recorded an increase of 30% of cabbages free from attack by the root fly (*Hylemyia brassicae*, Bch.) when treated at 10-day intervals with 1 pint of a solution of 1¼ oz. magnesium sulphate (in the form of cattle salts) per gallon.

See also Arsenates, p. 72, Borates, p. 75, Fluorides, p. 95, Fluosilicates, p. 95 and Kainit, p. 100.

Manganese Salts (see Arsenates, p. 72).

Menthol (Oil of Peppermint) ($C_{10}H_{19}OH$).

Crystalline.

Experiments in Soil.

ISOPODA.

Speyer and Owen (1924) found its toxic action to the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) very slow, but it was effective when mixed with soil in the proportion of 1 to 160.

Mercuric Chloride (Corrosive Sublimate) ($HgCl_2$).

Crystalline.

Mercuric chloride has been used principally in the control of cabbage root maggot and onion fly. It has been so successful for these that many authors have experimented with it as a control for other soil pests, but usually with negative results. Its action is probably on the eggs alone, and it appears possible that in the soil it is reduced to metallic mercury, which in the vapour phase is highly toxic to insect eggs (Gough 1938).

It suffers from two disadvantages: it is very poisonous to mammals and it quickly corrodes any metal vessel. For this reason it should always be mixed and applied in glass, porcelain or wooden vessels. In cold water it is rather difficult to get into solution, and a concentrated solution should first be made in hot water or in hydrochloric acid.

Experiments in Soil.

HEMIPTERA.

Aphidae.

Cutright (1925), using a solution of 1 oz./4 U.S. gals. (1·8 gm./l.) at the rate of 1 U.S. pint per plant, damaged asters without affecting the white aster root aphis (*Prociphilus erigeronensis*, Thos.). It was also ineffective at 1 oz./10 U.S. gals. (0·74 gm./l.) to control black peach aphis (*Anuraphis persicae-niger*, Smith) on peach trees.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923*a*) found a solution of 2 gm./l. used at 2 l. per tree was ineffective as a control for peach-tree borer (*Aegeria exitiosa*, Say), and seriously injured young trees. A mixture of corrosive sublimate (1 part) and hydrated lime (25 parts) applied at 5 teaspoonfuls per tree appeared to be effective in controlling the young larvae.

COLEOPTERA.

Scarabaeidae.

Corrosive sublimate was reported as ineffective by Davis (1920 *a*) for the white grub (*Lachnosterna* sp.) ; by Leach and Johnson (1925) in 0·1% solution for *Popillia japonica*, Newm., larvae at the roots of perennial plants ; by Zappe and Garman (1925) for Oriental beetle grubs (*Anomala orientalis*, Waterh.) in lawns ; and by Cottier (1932) at rates equivalent to 4–34 gm./sq. m. for the control of the New Zealand grass grub (*Odontria zealandica*, White).

Elateridae.

Gough (1942) found it was ineffective for the control of wireworms (*Agriotes* sp.) in pot experiments up to rates corresponding to 37 gm./sq. m.

Curculionidae.

French and Hammond (1926) also found a solution of 4 oz./10 gals. (2·5 gm./l.) ineffective for the control of the giant apple root borer (*Leptops hopei*, Fhs.) at 5 gals. per tree (57 gm./tree). Vasina (1927 *b*) stated that a solution of 2 gm. in 380 gm. water killed all pupae of the cabbage stem weevil (*Ceuthorrhynchus quadridens*, Panz.) in laboratory experiments.

Chrysomelidae.

Weigel and Doucette (1922) found a solution of ½ oz./3 U.S. gals. (1·2 gm./l.) at the rate of ½ U.S. pint per plant (0·3 gm./plant) useless for the control of the strawberry root worm (*Paria canella*, F.) on roses.

Cerambycidae.

According to an anonymous publication (New Mexico 1935), a 1/1000 solution applied at 1¼ U.S. gals./cu. ft. was ineffective for the control of the root borer (*Prionus californicus*, Motsch.).

DIPTERA.

Chironomidae and Mycetophilidae.

Thompson (1929) found a 1/1,000 solution poured on the soil in sufficient quantities to penetrate as far down as they occurred killed all immature stages of *Smittia byssina*, Schr., and *Sciara caesar*, Johannsen.

Psilidae.

Psila rosae, F. (Carrot Fly).

Gorham (1934) applied sublimate at 15 lb./ac. (2 gm./sq. m.) to control the carrot fly and reduced the average spring injury to 0·64% compared with 34·3% in the controls, and the autumn injury from 51·12% to 12·65%. Dustan (1930) recommended two applications of a solution of 1 oz./10 gals. (0·62 gm./l.) watered on to carrots at 800 gals./ac. (0·56 gm./sq. m.). Whitcomb (1938) obtained only moderate control with a solution of 1 oz./7½ U.S. gals. (1 gm./l.) and found that it stunted growth.

Anthomyiidae.

Hylemyia brassicae, Bch. (Cabbage Root Maggot).

Slingerland (1894) quoted an editorial in the "Country Gentleman" for 1864 in which a solution of 1 oz. of mercuric chloride in 4 gallons of water was recommended for the destruction of root maggots on cabbages. He also quoted a correspondent to "American Cultivator" for 1881 who said that all the London market gardeners secretly used a solution of $\frac{1}{4}$ oz. in 4 gals. of water, using enough to saturate the ground. Slingerland himself had little faith in the remedy, but suggested that it should be further tested. Brittain and Lowry (1916) only recorded a small reduction of the infestation compared with the controls with a solution of 4 oz./55 U.S. gals. (0·54 gm./l.). Caesar and Huckett (1920) described corrosive sublimate as the only substance to give satisfactory results in the control of root fly maggots. As 1/1,000 solutions to the soil only gave low kills of various stages in laboratory experiments, they came to the conclusion that it must have a repellent rather than a lethal effect. Brittain (1920, 1921, 1922, 1923, 1924 and 1927) carried out experiments with it over a number of years and found it always gave satisfactory results. He (1923) recommended two applications of 1/1,000 solution, one when the flies first appeared and a second about 10 days later. He found this concentration was lethal to eggs and earlier stages of the larvae, but at about the age of seven days the larvae became more resistant, and at 14 days old the results were very variable. He also used it mixed with clay (1/100) and clay and tobacco dust, both with successful results (1920, 1921, 1922).

Two or three applications at similar rates, *i.e.* 1/800–1/1,200, or 1 oz./8–10 gals., have been used successfully by Herrick (1923), Anon. (Pennsylvania 1925), Vasina (1927 *a*) (who stated that it killed the eggs but not the larvae), Anon. (New York 1928), Krasnyuk (1931), Miles (1931), Friend (1932 *a* and *b*), Langenbuch (1932), Edwards (1932 and 1935), Goffart (1933), Tomaszewski *et al.* (1934), Gasow (1935), Bourne and Whitcomb (1937), Wright (1938 *a*). K. M. Smith (1925), who first used it in England, did not find it satisfactory, though his results were not conclusive. Glasgow (1923) and Wright (1940 *b*) also found it gave a satisfactory control of the maggot in beds of brassica seedlings.

Hylemyia antiqua, Mg. (Onion Fly).

K. M. Smith (1923) found an application of 1 oz./10 gals. (0·6 gm./l.) applied at one cupful (about 200 cc. per plant) scarcely improved the yield of onions over the controls, though as the ground was very hard at the time, the treatment did not have a fair test. Flint and Compton (1925), using it at 1 oz./10 U.S. gals. (0·74 gm./l.), found three applications at one-day intervals effectively reduced the attack by onion maggots. Ruhmann (1925) and Dustan (1937) also used it successfully and recommended similar rates. Wright (1938 *b* and 1939), however, only obtained 45% of the original number of plants remaining in July, compared with 37% in the controls, after three applications of 1 oz. in 10 gals.

Trypetidae.

Thiem (1934) found a 0·25% solution applied to the soil at about 26 gm./sq. m. was ineffective for the control of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.). Wiesmann (1934) also found 5–10 l./sq. m. of a 0·6% solution (30–60 gm./sq. m.) was unsatisfactory for this purpose.

Syrphidae.

Wilcox (1927) obtained complete control of the narcissus bulb fly (*Merodon equestris*, F.) and good control of the lesser bulb fly (*Eumerus strigatus*, Fall.) with a solution of 1 oz./10 U.S. gals. (0·74 gm./l.) poured round the base of the plants at weekly intervals.

HYMENOPTERA.

Formicidae.

Walker and Anderson (1937) were unable to kill pavement ants (*Tetramorium caespitum*, L.) attacking egg-plants with solutions of 1/500–1/200, and the higher concentration also killed the plants.

MYRIOPODA.

Scutigerella immaculata, Newp. (Glasshouse Symphylid).

Thomas (1928) stated that sublimate solution killed large numbers of this Symphylid, but also damaged sweet pea seedlings. Kearns and Walton (1932) found that a solution of 1 oz. in 160 gals. (1/25,600) heavily watered on to tomato plants checked an attack of this pest which had developed by the migration of the larvae from the subsoil into the steam-sterilised top-soil. Speyer (1935) found 5 fl. oz. of 1/3,000–1/4,000 solution applied to plants in 6-inch pots killed all the Symphilids in four and five days, respectively.

SUMMARY.

Apart from its use in the control of root maggots, mercuric chloride appears to be of little value as a soil insecticide. Its success in the control of the glasshouse Symphilid (*Scutigerella immaculata*, Newp.) might be worth following up.

Mercurous Chloride (Calomel) (HgCl).

Crystalline

Like corrosive sublimate, this substance has been largely used as a control measure for root maggots, and attention was first drawn to its useful properties for this purpose by Glasgow (1929), who was carrying out experiments on several mercury compounds as possible substitutes for mercuric chloride. Calomel is insoluble in water and is less toxic to mammals than mercuric chloride. It is usually applied as a dust bulked with some inert material. It has also been applied as a suspension in water, and Gasow (1935) gave details of the effect of various substances (gelatine, glycerine and saponin) on such suspensions.

HEMIPTERA.

Coccidae.

Hosni and Shafik (1935) found a suspension of ½ oz./gal. was very effective for the control of the mealybug, *Pseudococcus brevipes*, Ckll., on the roots of *Phoenix* sp. when applied to infested plants before re-potting.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) found it ineffective at the rate of 1,500 lb./ac. (168 gm./sq. m.) for the control of *Popillia japonica*, Newm., larvae in pot experiments. Kerr (1940) also used it in suspension with gum arabic without success for the control of white grubs (*Lachnosterna* sp.) attacking strawberries.

Elateridae.

Hawkins (1936) applied a suspension of ⅛ oz. to 9-inch flower-pots (150 gm./sq. m.), but found it was not very effective for the control of the wireworm, *Agriotes mancus*, Say. Gough (1942) obtained only low kills of wireworms (*Agriotes* sp.) in pot experiments with calomel intimately mixed with the top 3 ins. (7·5 cm.) of soil up to rates corresponding to 5 cwt./ac. (625 gm./sq. m.).

DIPTERA.

Cecidomyiidae.

Tanabe and Sekiya (1930 and 1931) recommended a mercurous chloride suspension of 1/3,000–1/4,000 to control larvae of *Diplosis mori*, Yokoy., which was causing serious damage to young mulberry buds.

Chironomidae (?).

Fulton (1933) stated that only 100 adults of midge larvae which were damaging seedling tobacco plants emerged from soil treated with calomel, compared with 795 in the controls.

Bibionidae.

Edwards (1941) obtained no control of larvae of the fever fly (*Dilophus febrilis*, L.) in lawns treated with a 4% dust of mercurous chloride watered into the soil.

Psilidae.

Glasgow (1929) found two or three applications at weekly intervals of a suspension of 4 oz./10 U.S. gals. (3 gm./l.) resulted in 97 and 100% respectively of carrots free from attack by *Psila rosae*, F. Five weekly applications of a suspension of 1 oz./10 U.S. gals. (0·8 gm./l.) were necessary to give complete control. Whitcomb (1938) failed to control this insect with three applications of 1 oz./5 gals. (1·5 gm./l.), but found 2–4% dusts (bulked with lime or gypsum) gave fair control of light infestations but not of heavy.

Anthomyiidae.

Hylemyia brassicae, Bch. (Cabbage Root Maggot).

Glasgow (1929) obtained complete control of root grub attack on cauliflowers (compared with 82·5% attack in the checks) with a 4% dust drilled with the seed or used to coat it. Various workers (New York 1931, Friend 1932 *a*, Gasow 1935, Glasgow 1936) described experiments applying it in suspension at concentrations ranging from 1/300–1/2,000, but usually about 1/1,000, with success. Recent work suggests, however, that two to three applications of a 4% dust is more effective and simpler to apply (New York 1931, 1935, Friend 1932 *a* and *b*, Glasgow 1936, Wright 1938 *a*, 1940 *a*). The method, which has now become a common practice in Britain, as recommended by Wright (1938 *a*), is as follows :—Calomel should be applied with a hand duster, preferably of the bellows type, the nozzle being held close to the base of the plant and the 4% dust deposited in immediate contact with the stem where it enters the soil. About half a teaspoonful (2·8 gm.) should be applied per plant, and two applications, the first within four days of setting out, give a high degree of control. With plants one yard apart each way, 30 lb. dust/ac. (3 gm./sq. m.) is necessary.

Wright found no cases of injury to cauliflowers or other brassicas with the treatment at rates up to 35 lb./ac., and also found it more effective than corrosive sublimate. Tomaszewski *et al.* (1934), however, stated that it caused damage to plants and was not so successful as sublimate. Wright (1940 *b*) also found a 4% dust at 1 lb./60 yd. row gave effective control of the maggot on beds of brassica seedlings.

Hylemyia antiqua, Mg. (Onion Fly).

Glasgow (1929) used a 4% dust drilled with onion seeds and reduced loss of plants due to onion fly to 4·1%. Coating the seed was not an effective control. Dustan (1937) did not obtain such successful results with four applications of a 1/900 suspension (using sulphite lye to improve the suspension) watered on to the seedlings in sufficient quantities to penetrate 1 in. (2·5 cm.). He found it considerably less effective than mercuric chloride.

Wright (1938 *b* and 1939) recommended a 4% calomel dust as a seed dressing and recorded 91·5% plants remaining in July compared with 37% in the controls, and 45% for three applications of sublimate solution. Dusting the rows when the plants were in the seedling stage was also effective.

SUMMARY.

Like corrosive sublimate, calomel appears to have little action except as an ovicide. Where soil insects can be attacked in the egg stage, calomel would be worth trying.

Mercury Compounds other than Chlorides.

COLEOPTERA.

Scarabaeidae.

Downes (1928) found a proprietary seed dressing (containing Hydroxymercuric-chlorphenol) in solution at 1/400 had little effect on larvae of *Aphodius pardalis*, Lec., which was causing damage to lawns in British Columbia.

Lipp (1929) tested the following compounds in 4-inch flower-pots at 1,500 lb./ac. (168 gm./sq. m.) as poisons for *Popillia japonica*, Newm., grubs.

Mercuric borate	Successful
Mercuric phosphate..	Ineffective
Mercuric iodide	Successful
Mercurous iodide	Ineffective
Mercurous chromate..	Ineffective

Elateridae.

Gough (1942) only obtained a maximum of 45% kill of wireworms (*Agriotes* sp.) with phenyl mercuric acetate incorporated in the soil in pot experiments at rates up to 15 cwt./ac. (189 gm./sq. m.).

DIPTERA.

Anthomyiidae.

Flint and Compton (1925) found onion plots treated with mercuric cyanide were no better than the checks, though damage by the onion fly (*Hylemyia antiqua*, Mg.) was not severe in that season.

In an anonymous publication (New York 1935) it was stated that 2–3 light applications of dusts containing 4% oxide of mercury gave effective control of the cabbage root maggot (*Hylemyia brassicae*, Bch.). Dustan (1937) found methyl mercury chloride at 1/4,800 reduced attack by the onion maggot (*H. antiqua*, Mg.) from 23% in the check plots to 9·2% in the treated plots.

In an anonymous publication (Pennsylvania 1925) it is stated that phenol mercury compounds were tested in aqueous solutions and as solids bulked with clay carriers, but owing to the absence of serious infestation no definite data on their effectiveness were obtained.

Mesitylene ($(CH_3)_3C_6H_3$).

Liquid. S.G. 0·863 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): of uncertain toxicity.

Methallyl Chloride ($CH_2 : C(CH)_3CH_2Cl$).

Liquid.

COLEOPTERA.

Scarabaeidae.

Briejèr (1938) first suggested the use of this substance as an insecticide and stated that cockchafer larvae (*Melolontha* sp.) were killed with doses of 25 gm./sq. m. injected into four holes.

Elateridae.

Gough (1942) recorded kills of wireworms (*Agriotes* sp.) of 80–90% in pot experiments with applications of methallyl chloride at 187–374 cc./sq. yd. (190–382 gm./sq./m.). It was rather less effective than carbon disulphide under the same circumstances.

Methyl Alcohol (CH_3OH).

Liquid. S.G. 0·798 at 15° C.

HEMIPTERA.

Coccidae.

Saunders (1926) killed the mealybug, *Rhizoecus terrestris*, Newst., on acacia plants by injecting 2 cc. into the soil; the plant was unharmed.

Methyl Amine (CH_3NH_2).

Gas.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (24).

Methyl Aniline ($C_6H_5NH.CH_3$).

Liquid. S.G. 0·987 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic (3·7).

Methyl Bromide (CH_3Br).

Gas.

Methyl bromide has recently come to the fore as a fumigant for stored products. It has advantages over other fumigants of comparable toxicity in that less is absorbed by flour, in which greater penetration is obtained; less injury is caused to plant tissues, and it is virtually non-inflammable. Though only slightly soluble in water, it is appreciably so in oils (Shepard 1939). It has also proved useful as a soil fumigant, and quickly found its way into the official recommendations of the U.S. Department of Agriculture for this purpose.

COLEOPTERA.

Scarabaeidae.

Hamilton (1940) tested the action of methyl bromide on Asiatic beetle grubs (*Anomala orientalis*, Waterh.) attacking azalea plants. Three and five cc. doses of a solution of one part methyl bromide in five parts methyl or ethyl alcohol injected into the soil every 6 ins. (15 cm.), 3–5 ins. (7·5–12·5 cm.) deep (2–3½ cc./sq. ft. or 21–38 cc./sq. m.) killed all the grubs. Provided the temperature was not more than 68–70° F. the azaleas were unharmed, but at temperatures around 80° F. 25–30% of them were injured. He also used a solution of the same methyl bromide-alcohol mixture in water; 300 cc. of the mixture were dissolved in 3 U.S. gals. water and sprinkled over 30 and 15 sq. ft., giving 1 and 2 cc. methyl bromide/sq. ft. (11 and 22 cc./sq. m.). All the grubs were killed in one experiment and also many plants, but in a different type of container, 91% kill of the grubs was obtained at 1 cc./sq. ft. (11 cc./sq. m.) without injury to the plants.

For disinfesting soil balls containing *Popillia japonica*, Newm., larvae, the U.S. Department of Agriculture (1939 *a*) specify that soil balls or pots not more than

8 ins. (20 cm.) in diameter (later (1940 *a*) altered to not more than 12 ins. (30 cm.)) should be exposed for $2\frac{1}{2}$ hours at a temperature of at least 63° F. to an atmosphere of $2\frac{1}{2}$ lb. methyl bromide/1,000 cu. ft. A table showing the increase in dosage and period necessary at lower temperatures is given in a later announcement (1940 *b*). Strong (1940) has drawn attention to the fact that the adult beetles are less, and the eggs more, resistant than the larvae to methyl bromide.

Curculionidae.

Schwardt and Lincoln (1940) obtained 100% kill of larvae and 94% kill of adults of the alfalfa snout beetle (*Otiorrhynchus ligustici*, L.) with 7 cc. injections of methyl bromide 1 ft. apart at 953 lb./ac. (107 gm./sq. m.). It was not always possible to control the larvae in the top 6 ins. (15 cm.) by this means, and Lincoln *et al.* (1942) found that this could be accomplished by the addition of dichlorethyl ether (*q.v.*).

Livingstone *et al.* (1940) used an aqueous solution of 0·3 methyl bromide and 0·6% denatured alcohol to disinfest soil balls from white-fringed beetle larvae (*Pantomorus leucoloma*, Boh., and *P. peregrinus*, Buch.). Soil balls not more than 6 ins. (15 cm.) in diameter were buried in sand in a water-tight box and sprayed or sprinkled with 40 U.S. gals. of the solution/100 sq. ft. (49 cc./sq. m.). Complete control was obtained of the two species in 18 and 4 hours, respectively ; the difference was attributed to differences of soil rather than of specific resistance. Similar recommendations are made by the U.S. Department of Agriculture (1941). For disinfesting potting soil from this pest, they specify the application of 40 cc. methyl bromide/cu. yd. for 48 hours ; for soil balls, which should not be more than 3 ins. (7·5 cm.) in diameter, a dosage of $2\frac{1}{2}$ lb./1,000 cu. ft. for 4 hours at a temperature of at least 63° F. is necessary.

Methyl Iso-Butyl Ketone ($CH_3 . CO . C_4H_9$).

Liquid. S.G. 0·803 at 19° C.

COLEOPTERA.

Scarabaeidae.

Bell (1935) found it less toxic than carbon disulphide to the sugar-cane grub, *Dermolepida albohirtum*, Waterh.

Methyl Cyanide (CH_3CN).

Liquid. S.G. 0·791.

Experiments in Air.

Lehman (1933) recorded the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh., as 56 mg./l. for a 5-hour exposure ; it was 0·56 times as toxic as carbon disulphide.

Methyl Ethyl Ketone ($CH_3 . CO . C_2H_5$).

Liquid. S.G. 0·805 at 20° C.

Fleming (1925) : minimum lethal dose 124 mg./l.

Methyl Formate ($H . COO . CH_3$).

Liquid. S.G. 0·980.

Experiments in Air.

Lehman (1933) recorded the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh., as 12·5 mg./l. for a 5-hour exposure ; it was $2\frac{1}{2}$ times as toxic as carbon disulphide.

Methyl Iso-Propyl Phenol (see Thymol, p. 136).

Mowrah Meal.

Mowrah meal is the ground press-cake left after the removal of oil from seeds of *Bassia longifolia*, L. It has been reported as very effective in killing earthworms in the soil (Carlos 1926, Johnston 1927, quoted by Fleming 1942). Fleming (1942) only obtained 44% kill of *Popillia japonica*, Newm., larvae in soil treated at the rate of 8,000 lb./ac. (896 gm./sq. m.).

Mustard and Mustard Products.

Attention has probably been drawn to mustard as a possible soil insecticide by the commonly held idea that the plant itself has some effect on wireworms and the fact that Tattersfield and Roberts (1920) found mustard oil (Allyl isothiocyanate, p. 66) one of the most toxic substances to wireworms. Mustard oil is produced in the seeds of black mustard (from which domestic mustard is obtained) and not in those of white mustard (the plant grown as a catch crop or green-manure crop).

COLEOPTERA.

Elateridae.

Miles and Cohen (1939) tested mustard dross and golf-green mustard against wireworms. The first product contained 0·73 and the second 0·19% mustard oil, and both had been used in Norfolk on wireworm infested land. Mustard dross gave high kills in laboratory experiments at 1–2 tons/ac. (250–500 gm./sq. m.), but the golf-green mustard was unsuccessful up to 8 tons/ac. (2,000 gm./sq. m.). The addition of naphthalene to the dross increased its effectiveness.

Naphthalene (see p. 55).

β-Naphthalene Sulphonyl Chloride ($C_{10}H_7 . SO_2 . Cl$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·5% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 2 weeks.

α-Naphthoic Acid ($C_{10}H_7COOH$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of three weeks.

Naphthol ($C_{10}H_7OH$).

Crystalline.

Experiments in Air.

Fleming (1925) found both *α* and *β* forms non-toxic.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) found a saturated solution of the *α* form applied to the soil killed 75% of the larvae of *Popillia japonica*, Newm., but the treatment killed the plants on which the grubs were feeding. Fleming (1928) found soil mixed with 0·16% of either *α* or *β* forms was toxic to these larvae for an exposure of one week.

ISOPODA.

Speyer and Owen (1924) found soil mixed with 1 part in 173 of the α form was toxic to the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) but was slow in action, taking 2–8 days for 100% kill. The β form had little or no action.

Naphthyl Benzoate ($C_{10}H_7O . CO . C_6H_5$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) obtained no kill of *Popillia japonica*, Newm., larvae when a saturated solution was applied to the soil.

Fleming (1928) found soil mixed with 0·66% was toxic to *Popillia japonica*, Newm., larvae for an exposure period of 3 weeks.

Naphthylamine ($C_{10}H_7 . NH_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 2 weeks for the α form, and 1 week for the β form.

DIPTERA.

Anthomyiidae.

K. M. Smith (1923) used this substance successfully to control the onion fly (*Hylemyia antiqua*, Mg.), obtaining 75 lb. onions on the treated plots compared with 32 lb. on the control plots. It was, however, too expensive to be of economic value.

ISOPODA.

Speyer and Owen (1924) obtained 100% kill of the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) with soil mixed with α-naphthylamine in the proportion of 1 : 174, and its toxicity was maintained for 28 days.

Naphthylamine Hydrochloride ($C_{10}H_7 . NH_2 . HCl$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% of both α and β forms was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 2 weeks.

Nickel Salts (see Borates p. 75).

Nicotine ($C_{10}H_{14}N_2$).

Liquid. S.G. 1·010.

Pure nicotine is a colourless liquid alkaloid and, as normally extracted from tobacco, contains small amounts of related alkaloids. It rapidly turns yellow and finally dark brown on ageing, a process which does not appear to affect its insecticidal properties. It is frequently used in the form of nicotine sulphate and is a useful contact insecticide, especially for small soft-bodied insects such a Asphids. Nicotine is extremely poisonous to mammals both internally and externally.

Determination. See Sutherland *et al.* (1939).

Experiments in Air.

Fleming (1925) recorded 16 mg./l. as the minimum lethal dose for third-instar larvae of the Japanese beetle (*Popillia japonica*, Newm.). Leach and Thomson (1921) found a 0·16% solution used as a dip did not kill these larvae.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Gardner (1926) found that drenching the soil with a 1/600 dilution of nicotine sulphate (Black leaf 40) gave effective control of mealybugs, *Pseudococcus* sp. Saunders (1926) stated that a 1% nicotine solution killed the mealybug, *Rhizoecus terrestris*, Newst., without injuring the acacia plants on which they were feeding. 0·04 to 0·15 cc. injected into the soil was also successful.

Aphidae.

Cutright (1925) found one teaspoonful of nicotine in 1 U.S. gal. of soapy water applied to asters at 1 to 2 U.S. pints per plant killed numerous root Aphids (*Prociphilus erigeronensis*, Thos.), but it was necessary to repeat the treatment frequently. A mixture of 4 teaspoonfuls of 40% nicotine sulphate and 8 teaspoonfuls of engine oil emulsion mixed with 1 U.S. gal. of water and poured about the roots of peach trees at 1 to 8 U.S. pints per tree, was ineffective for the control of the black peach aphis (*Anuraphis persicae-niger*, Smith).

LEPIDOPTERA.

Noctuidae.

Hawley (1918) used a 1/400 solution of nicotine sulphate to drench the soil to control the hop borer (*Hydroecia immanis*, Gn.), but though it reduced the number of grubs, it was not sufficiently effective to be of value.

Crambidae.

Noble (1932) found 1 oz. of 40% nicotine sulphate diluted in 3 U.S. gals. water and applied at 1 gal./sq. yd. (5 gm./sq. m.) was ineffective for the control of sod webworms in lawns.

COLEOPTERA.

Scarabaeidae.

According to Decoppet (1920), black soap and nicotine had a marked action on cockchafer larvae (*Melolontha melolontha*, L.), but not sufficient to be an effective and economic control.

Curculionidae.

F. F. Smith (1932) stated that both nicotine sulphate and free nicotine in solution killed primulas and cyclamens without injuring vine weevil grubs (*Otiorrhynchus sulcatus*, F.).

English and Graham (1938) only obtained 9% kill of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) in soil balls dipped for 15 min. in a solution of 20 cc. nicotine sulphate/U.S. gal.

Chrysomelidae.

Weigel and Doucette (1922) obtained negative results in the control of the strawberry root worm (*Paria canella*, F.) attacking roses with 2 drops of nicotine sulphate in 225 cc. water per plant.

DIPTERA.

Tipulidae.

Gilmore and Milam (1934) controlled an outbreak of larvae of *Limnobia ultima*, O.-S., causing damage to tobacco seedlings, by drenching the beds with a solution of 10 cc. nicotine sulphate in 1 U.S. gal. water.

Mycetophilidae.

Speyer *et al.* (1939) obtained satisfactory control of larvae of *Plastosciara perniciosa*, Edw., and *Pnyxia scabiei*, Hopk., damaging young cucumber plants, by drenching the soil with an emulsion of sulphonated petroleum oil and 5% nicotine. This did not give satisfactory results in the cucumber beds themselves.

Bibionidae.

Horník and Nolč (1931) obtained 42 and 52% kill of larvae of *Bibio marci*, L., with 1 and 2% sprays of a tobacco extract containing 7% nicotine sulphate, applied at the rate of 55 gals./ac. (2 and 4 gm./sq. m.).

Psilidae.

K. M. Smith (1925) was able to reduce the infestation of carrot fly (*Psila rosae*, F.) from 70% in the controls to 35% in plots dusted once a fortnight with a 5% nicotine sulphate dust.

Anthomyiidae.

Hylemyia brassicae, Bch. (Cabbage Root Maggot).

Brittain (1920), using a 2%, and K. M. Smith (1925), using a 5% nicotine sulphate dust, both obtained unsatisfactory results.

H. antiqua, Mg. (Onion Fly).

K. M. Smith and Wadsworth (1921) treated small plots of onions with a solution of 1 fl. oz. nicotine in 5 gals. water and found it the most successful of all the treatments tried. K. M. Smith (1923) obtained nearly 50% increased yield of onions from plots treated with equal parts of nicotine dust and soap powder and bulked with chalk. Later (1925) he recorded 18% infested plants on a plot treated with a 5% nicotine sulphate dust compared with 51% on the corresponding untreated plot. Flint and Compton (1925), however, only obtained very slightly increased yields compared with the controls on plots treated with a 2% dust.

HYMENOPTERA.

Formicidae.

Walker and Anderson (1937) found a 3% nicotine dust ineffective for the control of the pavement ant, *Tetramorium caespitum*, L., attacking egg-plants.

MYRIOPODA.

Cory and O'Neill (1917) obtained a 90% kill of the hot-house millepede, *Orthomorpha gracilis*, Koch, within 3 ins. (7·5 cm.) of the surface if the ground was well drenched with a 1/750 to 1/1000 solution of 40% nicotine or 40% nicotine sulphate. Horsfall and Eyer (1921) obtained a considerably increased number of seedling plants in frames treated with 1/200 solution of nicotine sulphate or a 2% dust to control millepedes. In an anonymous publication (Pennsylvania 1925) it is stated that satisfactory results were obtained in the control of millepedes attacking lettuce in cold frames with a 1/500 solution of nicotine sulphate applied at 1 U.S. gal./2½ sq. ft. (15 gm./sq. m.) or a 2% nicotine dust washed into the soil a week before sowing. Orchard (1937) found a 1/2,000 solution of nicotine killed 80% of the millepedes, *Blaniulus guttulatus*, Bosc, and *Orthomorpha gracilis*, Koch, attacking the roots of cucumbers in nurseries. The remaining millepedes were brought to the surface and could be killed by spraying with a solution of the same strength. Thomas (1928) found a solution of nicotine sulphate ineffective for the control of the Symphylid, *Scutigerella immaculata*, Newp.

SUMMARY.

Apart from its success in the control of millepedes, nicotine has proved of little value as a soil insecticide.

3-Nitro-4-Amino Toluene ($CH_3.C_6H_3.NO_2NH_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to *Popillia japonica*, Newm., larvae for an exposure of 1 week.

Nitraniline ($NO_2C_6H_4NH_2$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): *o*- and *m*-forms non-toxic; *p*-form, of uncertain toxicity.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% of the *m*-form was toxic to *Popillia japonica*, Newm., larvae for an exposure of 3 weeks.

Nitrobenzaldehyde ($NO_2C_6H_4CHO$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): non-toxic.

Nitrobenzene ($C_6H_5NO_2$).

Liquid. S.G. 1·203 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (24). Fleming (1925): minimum lethal dose in air 22 mg./l; in water 800 mg./l.

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained negative results in the control of peach-tree borer (*Aegeria exitiosa*, Say) with ½ fl. oz. doses applied to peach trees.

COLEOPTERA.

Scarabaeidae.

Fleming (1926) found a solution of 3·5 gm./l. used as a dip for periods of 6–24 hours killed all larvae of *Popillia japonica*, Newm., at the roots of potted plants.

Elateridae.

Nitrobenzene has been frequently used as the toxic principle of poison baits for wireworms (Thomas 1930).

DIPTERA.

Anthomyiidae.

K. M. Smith (1923) tested nitrobenzene as a remedy for onion fly (*Hylemyia antiqua*, Mg.) and obtained an increase in the yield of onions on the treated plots (56 lb.) compared with the control plots (32 lb.); in later experiments (1925) he found a 2% dust in chalk was ineffective. The same dust applied to cabbages resulted in only 20% of the cabbages being attacked by root maggots (*H. brassicae*, Bch.) compared with 70% in the controls.

Nitrochlorbenzene ($C_6H_4ClNO_2$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): *o*- and *p*-forms of uncertain toxicity. Fleming (1925): *p*-form, minimum lethal dose 796 mg./l.; *o*-form, non-toxic.

Experiments in Soil.

HEMIPTERA.

Aphidae.

Marcovitch (1934) tested the *p*-form as a control measure for woolly apple aphis (*Eriosoma lanigerum*, Hsm.) but found that doses of 1/16 oz. injured the trees.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained 65–80% kill of the peach-tree borer (*Aegeria exitiosa*, Say) with 1 oz. applications to peach trees of *p*-nitrochlorbenzene, and 40–53% kills with ½ oz. doses. ½ oz. doses of the *o*-form gave 40% kill.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% of either the *o*- or *p*-forms was toxic to larvae of *Popillia japonica*, Newm., for an exposure of one week.

Nitro-o-cresol ($CH_3C_6H_3NO_2OH$).

DIPTERA.

Anthomyiidae.

K. M. Smith (1925) found it useless as a control measure for cabbage-root maggot (*Hylemyia brassicae*, Bch.) and onion maggot (*H. antiqua*, Mg.).

Nitromethane (CH_3NO_2).

Liquid. S.G. 1·144.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (710).

Nitronaphthalene ($C_{10}H_7NO_2$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): non-toxic.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% of the *a*-form was toxic to *Popillia japonica*, Newm., larvae for an exposure of 1 week.

1-Nitro 2-Naphthol ($NO_2C_{10}H_6OH$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·33% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 3 weeks.

Nitronaphthylamine ($NO_2C_{10}H_6NH_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 1 week.

p-Nitrophenetol ($C_2H_5O . C_6H_4 . NO_2$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 1 week.

Nitrophenol ($NO_2C_6H_4OH$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): *o*-nitrophenol highly toxic (6·5) ; *p*-nitrophenol non-toxic.

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) only obtained 13% kill of the peach-tree borer (*Aegeria exitiosa*, Say) with ½ oz. doses of the *o*-form per tree.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·5% of the *p*-form was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 2 weeks.

ISOPODA.

Speyer and Owen (1924) found soil mixed with the *o*-form in the proportion of 1/108 was toxic to the cucumber house woodlouse (*Armadillidium speyeri*, Jackson), and remained so for 26 days. The *p*-form was also toxic at that rate, but 100% kill was not obtained for 10 days.

Nitrotoluene ($NO_2C_6H_4CH_3$).

o- and *m*- liquid ; *p*- crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): *o*- and *p*-forms of uncertain toxicity. Fleming (1925): minimum lethal dose of *o*-form in air 44 mg./l. ; in water 582 mg./l.

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) only obtained 30% kill of peach-tree borers (*Aegeria exitiosa*, Say) with ½ oz. doses per tree.

Nitroxylene ($C_6H_3NO_2(CH_3)_2$).

Liquid.

Experiments in Air.

Tattersfield and Roberts (1920): of uncertain toxicity.

Orpiment (see Arsenious sulphide, p. 72).

Oxanilide ($C_6H_5NH . CO . CO . NH . C_6H_5$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·5% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 3 weeks.

Paraffin (see Kerosene, p. 101).

Paraldehyde ($(C_2H_4O)_3$).

Liquid. S.G. 0·999.

Experiments in Air.

Fleming (1925) : minimum lethal dose 248 mg./l.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) reported that an 8% solution watered on perennial plants killed them without affecting *Popillia japonica*, Newm., larvae attacking the roots.

Paris Green (see Arsenic Compounds, p. 71).

Pentachlorethane (CCl_3CHCl_2).

Liquid. S.G. 1·834.

Experiments in Water.

Fleming (1928) found solutions of it more toxic than carbon disulphide to larvae of *Popillia japonica*, Newm., when they were immersed in it.

Pentane (C_5H_{12}).

Liquid. S.G. 0·634.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (16,600).

Petroleum Oils and Distillates (excluding Kerosene).

As with the coal-tar distillates, there is considerable difficulty in the nomenclature of petroleum products, different workers having different names for the same substance or the same names for different substances. Foreign names are also confusing. The products themselves are liable to vary with the source from which they are derived and the processes and degree of refinement. They have been grouped here into the following categories :—

1. Petrol or gasoline, as used in internal combustion engines ; distillation range, 70–140° C.
2. Petroleum ether, solvent ; distillation range, 40–90° C.
3. Crude petroleum and petroleum oils of an unspecified nature.

Petrol (Gasoline).

Experiments in Soil.

ORTHOPTERA.

Gryllidae.

Hutson (1934) destroyed crickets (*Anurogryllus* sp. and *Gymnogryllus humeralis*, Wlk.) attacking young *Grevillea* plants by fumigation with petrol.

COLEOPTERA.

Scarabaeidae.

Swezey (1913) only obtained 20% kill of larvae of *Anomala orientalis*, Waterh., attacking sugar-cane in Hawaii with injections of 10 and 20 cc. on one, two or four sides of the stools. Cotton (1918) tested gasoline both alone and in conjunction with carbon disulphide as a remedy for white grubs (*Lachnosterna* sp.) attacking sugar-cane in Porto Rico, but found it injurious to the cane at rates at which it killed the grubs. Leefmans (1915) obtained 81% kill of cassava grubs (*Leucopholis*

rorida, F., and *Lepidiota stigma*, F.) with soil injections, each of 80 cc. gasoline per plant. The treatment was, however, very expensive. When mixed with carbon disulphide at various rates, the effectiveness of the latter was considerably reduced.

Chrysomelidae.

Feytaud (1932) mentioned fumigation with petrol as a useful emergency measure for the control of Colorado beetle adults (*Leptinotarsa decemlineata*, Say).

Elateridae.

According to Melander (1923) gasoline gave promising results as a method of killing wireworms previously concentrated to baits.

DIPTERA.

Trypetidae.

Wiesmann (1933) obtained 100% kill of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) in soil treated with 3 l./sq. m. In a field experiment on larvae, cherry trees were severely damaged, although only one fly emerged from under the treated trees.

HYMENOPTERA.

Formicidae.

Hutson (1933) recommended 1–2 pints of petrol/30 sq. ft. (204–408 cc./sq. m.) placed in shallow furrows or holes along plant beds before planting to control the root-eating ant, *Dorylus orientalis*, Westw.

Petrolenm Ether.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) stated that a saturated solution of petroleum ether in water had no effect on *Popillia japonica*, Newm., larvae when watered on to the soil about the roots of various perennial plants.

Crude Petroleum and Petroleum Oils of an Unspecified Nature.

COLEOPTERA.

Scarabaeidae.

D'Emmerez de Charmoy (1912) found a 7% petroleum emulsion was too expensive as a soil fumigant for larvae of *Lachnosterna smithi*, Arr., and other grubs attacking sugar-cane in Mauritius. A mixture of petroleum oil and creolin (see p. 36) was effective.

Elateridae.

Comstock and Slingerland (1892) tested a rather unstable emulsion consisting of one U.S. pint crude petroleum in whale-oil soap and water, diluted with four to five times its volume of water, as a remedy for wireworms, but the results were not promising.

DIPTERA.

Trypetidae.

Wiesmann (1933) obtained 100% kill of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) in pot experiments with crude petroleum (Rohöl) at 3 l./sq. m.

Phenanthrene ($C_{14}H_{10}$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): non-toxic.

Experiments in Soil.

ISOPODA.

Speyer and Owen (1924) found that it possessed only slight toxicity to the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when mixed with soil in the proportions of 1 : 140. Its action, moreover, was slow and irregular.

Phenylbromide (see Brombenzene, p. 77).

Phenylenediamine (Diaminobenzene) ($C_6H_4(NH_2)_2$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920) : *meta*-form non-toxic.

Phenylhydrazine ($C_6H_5NH \cdot NH_2$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920) : non-toxic.

Phloroglucinol (Trihydroxybenzene) ($C_6H_3(OH)_3$).

Crystalline.

ISOPODA.

Speyer and Owen (1924) reported that when mixed with soil in varying proportions it had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson).

Phosphates.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) tested the toxicity of the phosphates of barium, cobalt lithium and mercury (mercuric) mixed with soil at 1,500 lb./ac. (168 gm./sq. m.) to *Popillia japonica*, Newm., larvae in pot experiments, but found them all ineffective. Fleming (1942) also found acid phosphate of no practical value for the control of these grubs, even when applied at rates up to 8,000 lb./ac. (896 gm./sq. m.).

Elateridae.

Miles and Cohen (1938) and Gough (1942) have carried out experiments suggesting that superphosphate drilled near cereal seeds is of value in preventing wireworm attack.

Chrysomelidae.

Feytaud (1938) found applications of superphosphate of calcium at 2,000 kg./ha. (200 gm./sq. m.) caused only slight reductions of Colorado beetle larvae (*Leptinotarsa decemlineata*, Say) in pot experiments.

Phosphine (Phosphoretted Hydrogen) (PH_3).

Gas.

DIPTERA.

Experiments in Soil.

Trypetidae.

Wiesmann (1933) tested a proprietary substance reputed to give off phosphine when in contact with the soil to control pupae of the cherry fly (*Rhagoletis cerasi*, L.) but found it useless.

Picric Acid (see Trinitrophenol, p. 140).

Pine Tar Oil (see Wood Oils, p. 141).

Polychlorbenzene (see *o*-Dichlorbenzene, p. 88).

Polychlorpentane.

ISOPTERA.

Hockenyos (1939) tested polychlorpentanes (mainly consisting of tetrachlorpentane) as insecticides or repellents for termites. When mixed with soil up to the proportion of 1/500, this substance caused no deaths within six days.

Potassium Antimonate (K_3SbO_4).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) found it ineffective for the control of Popillia japonica, Newm., larvae in pot experiments at 1,500 lb./ac. (168 gm./sq. m.).

Potassium Chlorate ($KClO_3$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) found it ineffective for the control of *Popillia japonica*, Newm., larvae in pot experiments at 1,500 lb./ac. (168 gm./sq. m.).

Potassium Chloride (Muriate of Potash) (KCl).

Crystalline.

Muriate of potash is a well known potassic fertiliser. The peculiar toxicity of both the potassium and chlorine ions to wireworms and cockchafer larvae noted by Subklew (1934, 1935, 1936 *a*, *b*) has already been mentioned under Kainit (p. 100).

Experiments in Soil.

COLEOPTERA.

Elateridae.

Comstock and Slingerland (1892) reported that it was necessary to apply it at the rate of 4–6 tons/acre (1,408–2,112 gm./sq. m.) before it had any effect on wireworms. This is 20–100 times the normal rates of use as a fertiliser.

Potassium Cobaltinitrite ($2Co(NO_2)_3 \cdot 6KNO_2 \cdot 3H_2O$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) found it ineffective for the control of *Popillia japonica*, Newm., larvae in pot experiments at 1,500 lb./ac. (168 gm./sq. m.).

Potassium Cyanide (KCN).

Crystalline.

Like the sodium salt, potassium cyanide is used as a solid and in solution. Mammelle (1910) suggested injecting a 20% solution with a Vermorel injector in holes 10–20 cm. deep, using 8–10 cc. per hole and 6–15 holes/sq.m. (15–20 gm./sq. m.).

HEMIPTERA.

Aphidae.

Reppert *et al.* (1922) destroyed woolly apple aphis (*Eriosoma lanigerum*, Hsm.) infestations on nursery stock with applications of ¼–½ oz. (7–14 gm.) cyanide per tree, but the trees were severely injured.

COLEOPTERA.

Scarabaeidae.

Swezey (1913) attempted unsuccessfully to control Oriental beetle larvae (*Anomala orientalis*, Waterh.) attacking sugar-cane in Hawaii by applying 5–20 cc. per stool of a solution containing 1 lb. cyanide/U.S. gal. (119 gm./l.). Leefmans (1915) found 2½ and 5 gm. applied in two holes, one on each side of cassava plants, only gave 6–38% kill of the cassava grubs (*Leucopholis rorida*, F., and *Lepidiota stigma*, F.). 20–40 cc. of a solution of 200 gm./l. applied under the plant gave only 13–27% kills. Jarvis (1916) obtained good results in the control of cane-beetle grubs (*Dermolepida albohirtum*, Waterh.) with the Mammelle method, applying two ½-oz. (14 cc.) injections of a solution of 7 oz./qt. on each side of the stool. He also obtained 100% kill of the grubs using a solution of 1 lb./200 gals. (0·5 gm./l.). The cane showed slight wilting of the leaves but recovered. Cotton (1918), using up to 50 cc. per stool of a solution of 200 gm./l., obtained only 39% kill of white grubs (*Lachnosterna* sp.) attacking sugar-cane in Porto Rico. Wolcott (1924), also in Porto Rico, found that cyanide did not kill any fully grown white grubs (*Lachnosterna* sp.) when applied up to 200 lb./ac. (22 gm./sq. m.). 70% kill was obtained with 500 lb./ac. (56 gm./sq. m.), but 100 lb./ac. (11 gm./sq. m.) gave 80% kill of second-instar larvae.

Chrysomelidae.

Feytaud (1932) found a solution of 5 gm./l. at 2 l./sq. m. (10 gm./sq. m.) was useless to control adults and larvae of the Colorado beetle (*Leptinotarsa decemlineata*, Say).

DIPTERA.

Cecidomyiidae.

Sjöberg (1936) recommended potassium cyanide at 1 and 2 gm./sq. m. for the control of cocoons of the wheat gall-midge (*Contarinia tritici*, Kby.).

SUMMARY.

Potassium cyanide has not been so extensively nor so successfully used as sodium cyanide. It has usually been used in solution, applied in small amounts close to plants being attacked by insects.

Potassium Nitrate (Saltpetre) (KNO_3).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Jarvis (1916) obtained negative results in the control of the sugar-cane grub (*Dermolepida albohirtum*, Waterh.) with a solution of 1 lb. potassium nitrate per litre, watered on to the soil.

Elateridae.

Malenotti (1927) found potassium nitrate useless as a control measure for wireworms when broadcast on the surface, but it had some value as a protectant for the seed.

Potassium Perchlorate ($KClO_4$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Lipp (1929) found it ineffective for the control of *Popillia japonica*, Newm., larvae in pot experiments at 1,500 lb./ac. (168 gm./sq. m.).

Potassium Permanganate ($KMnO_4$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Decoppet (1920) stated that according to information provided by Dr. Schneider-Orelli, potassium permanganate applied to the soil in 2% solution at 500 cc./sq. m. (10 gm./sq. m.) was without effect on cockchafer larvae (*Melolontha melolontha*, L.).

DIPTERA.

Tipulidae.

Gilmore and Milam (1934) found a solution of 4 gm. potassium permanganate in 1 U.S. gal. water used as a drench for tobacco seedling beds effectively controlled larvae of *Limnophila ultima*, O.-S., causing damage by tunnelling in the soil.

Psilidae.

K. M. Smith and Wadsworth (1921) found five applications of a solution of 1 oz. in 2 gals. water applied to rows of young carrots was ineffective in preventing or controlling attack by the carrot fly (*Psila rosae*, F.).

Anthomyiidae.

The same authors reported that six applications of the solution to onion rows resulted in 55% of the plants being free from attack by the onion fly (*Hylemyia antiqua*, Mg.).

Potassium Sulphate (K_2SO_4).

Crystalline. A potassic fertiliser.

COLEOPTERA.

Chrysomelidae.

Feytaud (1938) found applications of 1,200 kg./ha. (120 gm./sq. m.) caused only slight reductions of Colorado beetle larvae (*Leptinotarsa decemlineata*, Say) in pot experiments.

Potassium Sulphide ($K_2S.5H_2O$).

Crystalline.

DIPTERA.

Anthomyiidae.

Goff (1889) found no reduction in the number of larvae of the cabbage-root fly (*Hylemyia brassicae*, Bch.) at the roots of plants treated with ¼ U.S. pint of a solution of ¼ oz./U.S. gal. of potassium sulphide. At 1 oz./gal. two teaspoonfuls per plant injured the plants.

Mycetophilidae.

Speyer (1923 *a*) was unable to control larvae of *Pnyxia scabiei*, Hopk., a pest of cucumbers, with two applications of 100 cc. per pot of ½, 1 and 2% solutions.

Potassium Xanthate ($C_2H_5O.CS.SK$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of one week.

MYRIOPODA.

An anonymous author (California, 1926) failed to control the glasshouse Symphylid (*Scutigerella immaculata*, Newp.) in asparagus fields with potassium xanthate.

Michelbacher (1932) tested it in small plots against the same pest; mixed with an equal amount of sulphur, 62% kill was obtained at 2,400 lb./ac. (269 gm./sq. m.), though there was a considerable difference between duplicate plots.

MISCELLANEOUS.

Muir and Swezey (1926) found potassium xanthate promising as a control for various soil pests in Hawaii.

For other Potassium Salts see Cobalt Compounds, p. 84, Fluosilicates, p. 95.

Propylene Derivatives.

COLEOPTERA.

Scarabaeidae.

Bell (1935) found propylene chlorhydrin, propylene dichloride, and propylene oxide all less toxic to sugar-cane grubs (*Dermolepida albohirtum*, Waterh.) than carbon disulphide.

Pseudocumene (Trimethylbenzene) ($C_6H_3(CH_3)_3$).

Liquid. S.G. 0·879 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (95).

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) stated that 2 cc. injections into the soil of a small pot killed the mealybug (*Rhizoecus terrestris*, Newst.).

Pyrethrum.

Pyrethrum is the powder (or an extract made from it) ground from the *Pyrethrum* flower. Much research has been done on the nature of the active principles contained in it, which are known as pyrethrins. It is one of the most important of the contact insecticides and has the advantage that it is non-poisonous to mammals.

Experiments in Soil.

LEPIDOPTERA.

Crambidae.

Applying a diluted extract (1/640) at 1 U.S. gal./sq. yd., Noble (1932) brought the larvae to the surface, where they died (approx. 7 cc. extract/sq. m.). Stone and Elmore (1937) also found the larvae came to the surface after treatment at the same rate, but very few were killed by it. North and Thompson (1933), using a 1/592 dilution at 1 U.S. gal./sq. yd. (8 cc./sq. m.), estimated the damage caused to a treated lawn by the larvae at 43 and 57 units compared with 86 units of damage to the untreated area. Jewett (1939) at similar rates (1/640 and approx. 8 cc./sq. m.) obtained kills of 90–96% in three successive seasons. Bohart (1940) also obtained kills approaching 100% with a 1/400 dilution applied at 1 U.S. gal./sq. yd. (11 cc. extract/sq. m.).

COLEOPTERA.

Elateridae.

Headlee (1930) studied the effect of pouring ¼ U.S. pint of a diluted pyrethrum preparation containing 0·083 to 0·125% toxic principle around the bases of plants infested with wireworms. He obtained poor results in clay soils but up to 78% kill in sandy loams. Only low kills were obtained in laboratory experiments. No apparent damage was caused to a wide range of plants. He also investigated the filtering action of the soil on the extract and found that the surface tension of the filtrate steadily increased the greater the depth of soil through which it had passed.

This was due to the taking up of the soap (sodium oleate) in the preparation. Toxicity tests of the filtrate to *Aphis rumicis*, F., showed a rapid diminution of toxicity up to 4 ins. (10 cm.) and a slow but steady diminution thereafter. There was no loss of toxicity when washed sand was used instead of soil. Later (1931) he stated that pyrethrum rendered miscible with water by the addition of a sulphonated oil was able to penetrate the soil with little loss of toxicity, and a much higher mortality was obtained.

Pepper (1937) obtained negative results with a 1/200 dilution of pyrethrum extract applied to brassicas at 1 U.S. pint per plant.

Curculionidae.

English and Graham (1938) only obtained a 20% kill of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) by immersing soil balls containing larvae in a solution of 20 gm./U.S. gal.

DIPTERA.

Cecidomyiidae.

Mühlow and Sjöberg (1937) found no reduction of wheat gall-midges (*Contarinia tritici*, Kby., and *Sitodiplosis mosellana*, Géh.) on plots dusted with pyrethrum powder. A miscible kerosene extract diluted to 1/30 and sprayed on the plots at 1 gal./100 sq. yd. (approx. 2 cc. extract/sq. m.) subsequently reduced the percentage of infested ears from 16 in the controls to 7 in the treated plots. A 1% dilution in water applied at 1 and 2 gal./100 sq. yds. reduced the percentage from 15 to 9.

MYRIOPODA.

C. A. Thomas (1928) found a proprietary pyrethrum extract ineffective for the control of *Scutigerella immaculata*, Newp.

The Addition of Pyrethrum to other Substances.

Carbon Disulphide.

Burdette (1932) showed that the addition of pyrethrum to carbon disulphide emulsions enhanced their toxicity to wireworms attracted by trap crops. Pepper (1937), however, found such mixtures to be of little value in the control of wireworms about the roots of brassicas.

SUMMARY.

Pyrethrum would appear to be unsuitable as a soil insecticide except, possibly, for insects living near the surface such as Crambid larvae. For these, rates of 7–11 cc. extract/sq. m. have given good results.

Pyridine (C_5H_5N).

Liquid. S.G. 0·990.

Determination (see Daroga and Pollard (1941 *a*)).

Experiments in Air.

Tattersfield and Roberts (1920): moderately toxic (76). Fleming (1925): minimum lethal dose 124 mg./l. Lehman (1933) recorded the median lethal dose (50% kill) for the wireworm, *Pheletes californicus*, Mannh., as 5·89 mg./l. for an exposure of 5 hours; it was 5·3 times as toxic as carbon disulphide.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) found a 1% solution of pyridine watered on the soil of a small flower-pot killed the mealybug, *Rhizoecus terrestris*, Newst.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) reported that a 3% solution had no effect on larvae of *Popillia japonica*, Newm., when watered on to the soil about the roots of perennial plants ; the plants were killed.

Elateridae.

Peterson (1917) obtained negative results with pyridine alone and in conjunction with sodium sulphocarbonate or lime-sulphur in the control of wireworms.

Curculionidae.

F. F. Smith (1932) found solutions of pyridine, in varying concentrations, had no effect on larvae of the vine weevil (*Otiorrhynchus sulcatus*, F.) when watered on to the soil, and the solutions also injured cyclamens and primulas, on which the larvae were feeding.

DIPTERA.

Anthomyiidae.

Brittain (1921, 1922) reported appreciable reductions in the percentage of cabbage plants attacked by the root fly (*Hylemyia brassicae*, Bch.) on plots treated with pyridine (5%) absorbed in either clay or charcoal (95%). He also (1923) obtained promising results with crude pyridine bases.

Trypetidae.

Wiesmann (1933) treated an area under a cherry tree infested with larvae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) with 5 l./sq. m. of an 8% pyridine solution (396 gm./sq. m.). Only one fly emerged and no damage was done to the tree. Later (1934) he obtained good results in the control of pupae with 10 l./sq. m. of a 5% solution (495 gm./sq. m.). Thiem (1939) obtained good results in the control of the pupae with a 1% solution at 14 l./sq. m. (139 gm./sq. m.) in one season, but poor results the following year.

Pyrocatechol ($C_6H_4(OH)_2$).

Crystalline.

ISOPODA.

Speyer and Owen (1924) found it had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when mixed with the soil at high rates.

Pyrogallol ($C_6H_3(OH)_3$).

Crystalline.

ISOPODA.

Speyer and Owen (1924) found it had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when mixed with the soil at high rates.

Pyroligneous Acid.

Pyroligneous acid is the aqueous distillate resulting from the destructive distillation of wood. It contains methyl alcohol, mixed with acetic acid and acetone and a little methyl acetate.

HEMIPTERA.

Coccidae.

Saunders (1926) reported that a 5% solution killed the mealybug, *Rhizoecus terrestris*, Newst., when watered on to the soil.

Quassia.

Quassia chips are derived from the wood of the shrubs, *Quassia amara*, L., or *Aeschrion excelsa*, Swz., both of the family Simarubaceae (Shepard, 1939). For

insecticidal purposes the chips are extracted in water; it is not an insecticide of great importance.

DIPTERA.

Anthomyiidae.

Krasnyuk (1931) found a quassia and soap solution applied to cabbage plants had very little effect on the percentage of plants attacked by the root fly (Hylemyia brassicae, Bch.).

Quinol (see Hydroquinone, p. 100).

Resorcinol ($C_6H_4(OH)_2$).

Crystalline.

ISOPODA.

Speyer and Owen (1924) found it had little or no action on the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) when mixed with the soil at high rates.

Rhodanates (see Thiocyanates, p. 136).

Saltpetre (see Potassium Nitrate, p. 125).

Silico Fluorides (see Fluosilicates, p. 95).

Soap.

COLEOPTERA.

Curculionidae.

Vasina (1927 *b*) treated soil with a solution of 15 gm. soft soap per 380 gm. water to control pupae of the cabbage stem weevil (*Ceuthorrhynchus quadridens*, Panz.). Only six adults out of 30 pupae emerged from the treated soil, compared with 28 out of 30 in the control.

DIPTERA.

Anthomyiidae.

K. M. Smith and Wadsworth (1921) and K. M. Smith (1923) obtained marked increases in the yields of onions on plots treated with 1 oz. resin soap solution in 2 gals. water.

Vasina (1927 *a*) and Krasnyuk (1931) both found applications of soap solution to cabbages ineffective as a control measure for the root fly (*Hylemyia brassicae*, Bch.).

Sodium Benzene Sulphonate ($C_6H_5SO_3Na$).

Experiments in Air.

Fleming (1925): non-toxic up to 796 mg./l.

Sodium Bisulphite (Sodium Hydrogen Sulphite) ($NaHSO_3$).

Crystalline.

COLEOPTERA.

Chrysomelidae.

Feytaud (1932) found a commercial solution applied to the soil at 1 l./sq. m. of little value for controlling Colorado beetles (*Leptinotarsa decemlineata*, Say).

Sodium Chloride (Common Salt) (NaCl).

Crystalline.

Experiments in Water.

Leach and Thomson (1921) found a 5% solution did not kill *Popillia japonica*, Newm., larvae when they were dipped in it.

Experiments in Soil.

LEPIDOPTERA.

Noctuidae.

Hawley (1918) treated hop hills with 3 U.S. quarts of a saturated salt solution to control the hop borer (*Hydroecia immanis*, Gn.) without any effect; the vines were killed by the treatment.

COLEOPTERA.

Elateridae.

Comstock and Slingerland (1892) tested salt as a remedy for wireworms but found that it was not effective below 6–8 tons/acre (1,500–2,000 gm./sq. m.), at which rate it was very destructive to vegetation. Hawkins (1936) did experiments in Maine, using it at 700–800 lb./ac. (78–90 gm./sq. m.), to control the wireworm, *Agriotes mancus*, Say, but found it useless. It may be worth mentioning here that many British farmers are convinced of its value in the control of wireworms.

DIPTERA.

Anthomyiidae.

Brittain (1920, 1921) found half-saturated and saturated salt solutions applied to cabbage plants had no effect on the degree of infestation by the root fly (*Hylemyia brassicae*, Bch.).

Sodium Cyanide (see p. 62).

Sodium Xanthate ($C_2H_5OCSSNa$).

This compound is produced when carbon disulphide is added slowly to a mixture of sodium hydroxide and alcohol. It decomposes in the presence of a weak acid giving off carbon disulphide.

Experiments in Water.

Leach and Thomson (1921) found dipping the larvae of *Popillia japonica*, Newm., into a 1·5% solution for 3 hours had no effect on them, but a mixture of 0·25% xanthate and 0·67% acetic acid killed all the grubs within 2 hours.

Sodium 1-Naphthol 4-Sulphonate ($C_{10}H_6OHSO_3Na$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·33% was toxic to *Popillia japonica*, Newm., larvae for an exposure of 3 weeks.

Sodium p-Toluene Sulphonate ($CH_3C_6H_4SO_3Na$).

Experiments in Air.

Fleming (1925): non-toxic up to 796 mg./l.

For other Sodium Salts (see Borates, p. 75, Arsenic Compounds, p. 72, Fluorides, p. 95, Fluosilicates, p. 95, Sulphocarbonates, p. 132).

Soot.

A very variable product usually consisting mainly of carbon with small quantities of nitrogen in the form of ammonium chloride and a small amount of tar. Its deterrent properties to insects are said to depend on its sulphur content.

COLEOPTERA.

Scarabaeidae.

According to Thompson (1934), a dressing of 25 cwt. soot/ac. (315 gm./sq. m.) before ploughing appeared to give effective control of cockchafer larvae (*Melolontha melolontha*, L.).

Anthomyiidae.

Soot is widely used and recommended by small-holders and gardeners as a remedy for cabbage and onion root maggots (and also carrot fly—Psilidae). K. M. Smith and Wadsworth (1921) found six applications of soot dusted over onion rows had very little effect on the incidence of root fly attack (*Hylemyia antiqua*, Mg.), as only 16% of the plants were not damaged.

Strontium Salts (see Borates, p. 75, Fluorides, p. 95).

Sulphocarbonates (Thiocarbonates) of Sodium and Potassium ($Na_2CS_3H_2O$ and K_2CS_3).

Dumas (1874) first proposed the use of potassium sulphocarbonate as a soil insecticide for the Phylloxera of the vine. This substance is soluble in water, forming a dark red solution which is diluted for application. The strength of the solution is sometimes expressed as degrees Baumé (Bé °), a measure calculated from the specific gravity. Under the action of carbon dioxide the sulphocarbonate decomposes, liberating carbon disulphide and a lesser amount of sulphuretted hydrogen.

Molinas (1914) advocated it strongly and advised 1% by volume of a commercial solution for the control of slugs, cutworms, wireworms and millepedes. Leach and Thomson (1921) describe a method for the preparation of the sodium salt which acts similarly. They found that the addition of a small quantity of a weak acid, such as acetic, by encouraging the production of carbon disulphide, enhanced the toxicity of solutions to naked larvae of the Japanese beetle.

HEMIPTERA.

Coccidae.

Saunders (1926) in pot experiments found a 1% solution of potassium sulphocarbonate, which was the most satisfactory, or a 5% solution of sodium or calcium sulphocarbonates, killed the mealybug, *Rhizoecus terrestris*, Newst., without injuring the Acacia plants on which they were feeding.

Aphidae.

Krassilstchik (1915) recommended 8 to 11 gals. of a 4% solution poured over the previously exposed roots of apple trees to control woolly apple aphis (*Eriosoma lanigerum*, Hsm.). Details of the method of application to control the vine Phylloxera (*Phylloxera vastatrix*, Planch.) have been given by several French authors in the latter part of the nineteenth century, among whom Girard (1883) may be cited as a random example.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained inconclusive results in the control of peach tree borer (*Aegeria exitiosa*, Say) with ½ to 1 fl. oz. of a concentrated solution poured on the ground near peach trees.

Cossidae.

Jean (1922) controlled larvae of *Hypopta caestrum*, Hb., attacking asparagus roots by pouring on a solution of potassium sulphocarbonate of 250 to 500 gm./hectolitre either in small channels or in four holes, each 25 cm. deep, per sq. metre.

COLEOPTERA.

Scarabaeidae.

Leach and Thomson (1921) found that applications of sodium sulphocarbonate at rates sufficient to kill larvae of *Popillia japonica*, Newm., also seriously damaged the roots of conifers. 100% kill of larvae in soil balls was obtained five days after dipping the balls in a solution of 30 cc./U.S. gal. for 30 mins. There was no advantage in adding acetic acid to encourage decomposition. According to Decoppet (1920)

a 2% solution of the potassium salt applied at 70 gm./sq. m. was ineffective in controlling cockchafer larvae (*Melolontha melolontha*, L.). Lopez (1931 *b*) obtained good results in the control of white grubs (*Leucopholis irrorata*, Chevr.) with potassium sulphocarbonate in laboratory experiments, but found the treatment less satisfactory and very expensive in the field. After treating 100-ft. rows of sugarcane which had been destroyed by the grubs with 28 l./row, he found 43% fewer grubs in the treated rows than in the untreated rows. Hermans (1932) was unable to control May-grubs (*Melolontha* sp.) in the soil with concentrations below 7½%, at which strength the grass was killed.

Elateridae.

Peterson (1917) found sodium sulphocarbonate, alone and with pyridine, ineffective for the control of wireworms.

Curculionidae.

French and Hammond (1926) obtained good results in the control of the apple root borer (*Leptops hopei*, Fhs.) with 1½ to 3% solutions of potassium sulphocarbonate applied at 8 gals. per tree in winter when the soil was saturated, but the treatment was ineffective in the summer even with applications of 36 gals. per tree. 6 gals. of sodium sulphocarbonate was of no value. F. F. Smith (1932) found solutions of potassium sulphocarbonate ineffective for the control of the black vine weevil (*Otiorrhynchus sulcatus*, F.) at concentrations tolerated by the host plants, cyclamens and primulas.

Cerambycidae.

Pussard (1933) controlled the Cerambycid, *Vesperus strepens*, F., attacking the roots of carnations, by watering the soil with a 2% solution of potassium sulphocarbonate. In an anonymous publication (New Mexico 1935), 100% kill of larvae of *Prionus californicus*, Motsch., caged in artificial shelters buried in trenches, with a solution of potassium sulphocarbonate of 1 oz./U.S. gal./cu. ft. was reported.

DIPTERA.

Psilidae.

K. M. Smith and Wadsworth (1921) obtained complete freedom from attack by carrot fly (*Psila rosae*, F.) on plots treated with four applications of sodium sulphocarbonate at 1 oz./gal. and applied at 2 oz./12 sq. yd.

Anthomyiidae.

Solutions of the same strength as for carrot fly applied to onions to reduce attack by the onion fly (*Hylemyia antiqua*, Mg.) only resulted in a slight increase of yield (Smith and Wadsworth, 1921).

SUMMARY.

Apart from the original experiments on vine Phylloxera comparatively few successful results have been reported for this substance.

Sulphur (S).

HEMIPTERA.

Aphidae.

Cutright (1925) found 4 oz. (112 gm.) of ground sulphur dug into the soil around the roots of asters had no effect on the white aster root aphis (*Prociphilus erigeronensis*, Thos.). Applied to peach trees to control the black peach aphis (*Anuraphis persicae-niger*, Smith) at 1–16 lb. per tree (½ to 8 kg.) it killed nearly all the trees.

COLEOPTERA.

Scarabaeidae.

Cottier (1932) applied a product containing 21% free sulphur to small plots as top dressing at 1,200 lb./ac. (28 gm./sq. m.) without any effect on the New Zealand

grass grub (*Odontria zealandica*, White). In pot experiments sulphur applied at 6 tons/ac. (1,510 gm./sq. m.) was equally ineffective.

Elateridae.

Campbell and Stone (1932) found that applications of sulphur up to 1,000 lb./ac. (112 gm./sq. m.) in field experiments neither reduced the numbers of wireworms (*Pheletes californicus*, Mannh.), nor diminished damage to potatoes, although it materially reduced the *p*H of the soil. Hawkins (1936) obtained 50% kill of wireworms in a pot experiment after 15 days' exposure and a complete kill after 30 days with 2 oz. sulphur applied to a 6-in. pot (approximately 3,100 gm./sq. m.).

DIPTERA.

Anthomyiidae.

K. M. Smith and Wadsworth (1921) obtained an increased yield of onions from a plot treated with a suspension of sulphur (2 oz.) in soft soap (1 oz.)/2 gals. water sprayed on the onion beds to control attack by the onion fly (*Hylemyia antiqua*, Mg.).

MYRIOPODA.

Michelbacher (1932) found a mixture of sulphur and hydrated lime applied to small plots at 1,200 lb./ac. (135 gm./sq. m.) useless for the control of the glasshouse Symphylid (*Scutigerella immaculata*, Newp.). McLeod and Butcher (1934) stated that damage to potatoes by the millepede, *Diploiulus londinensis coeruleocinctus*, Wood (and also larvae of *Sciara* sp.—Diptera), appeared to be reduced under certain conditions by applying sulphur at 150 to 600 lb./ac. (17 to 67 gm./sq. m.), provided the soil *p*H was reduced below 5. It was not, however, a satisfactory control.

MISCELLANEOUS.

According to Bulger (1928), 2,000 lb./ac. (224 gm./sq. m.) was required to reduce the soil *p*H to 2·8, and even this degree of acidity was tolerated by ants, cutworms, white grubs and wireworms. It was also harmful to plants, and there was no evidence that sulphuric acid could be produced in the soil in quantities approaching those of insecticidal value. With well-buffered soils even 4,000 lb./ac. (448 gm./sq. m.) only produced a very slight drop in *p*H.

Addition of other Substances to Sulphur.

Nicotine, Brittain (1920).
Potassium xanthate (see p. 127), Michelbacher (1932).
Tobacco dust (see p. 138), Hawley (1918).

Sulphuric Acid (H_2SO_4).

Liquid. S.G. 1·834 at 4° C.

COLEOPTERA.

Scarabaeidae.

Davis (1920 *a*) applied solutions of 1/96 at 2,616 U.S. gals./ac. (46 gm./sq. m.), 1/48 at 1,308 U.S. gals./ac. (45 gm./sq. m.), and 1/24 at 872 U.S. gals./ac. (62 gm./sq. m.), but never obtained more than 10% kill of *Popillia japonica*, Newm., larvae.

DIPTERA.

Trypetidae.

Wiesmann (1933) obtained 75% kill of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) with 5 l./sq. m. of a 30% dilution (2,745 gm./sq. m.).

Sylvinite.

Sylvinite is a naturally occurring compound containing potassium and is primarily used as a potassic fertiliser.

DIPTERA.

Cecidomyiidae.

Olombel (1931) stated that cauliflowers grown on soil treated with sylvinite at 1,200–1,500 kg./ha. (120–150 gm./sq. m.) were less severely attacked by the gall-midge, *Contarinia torquens*, de Meij.

Terpenes (see Leach and Johnson, 1925, under Wormseed Oil, p. 142).

Tetrachlorethane (Acetylene Tetrachloride) ($CHCl_2CHCl_2$).

Liquid. S.G. 1·58 at 25° C.

ORTHOPTERA.

Gryllidae.

Feytaud (1933 *b*) reported that soil injections of 40 gm./sq. m. of tetrachlorethane gave effective control of the mole cricket, *Gryllotalpa gryllotalpa*, L.

HEMIPTERA.

Coccidae.

Saunders (1926) found watering the soil with 1% solution of miscible tetrachlorethane killed mealybugs, *Rhizoecus terrestris*, Newst., without injuring Acacia plants.

Aphidae.

Börner and Thiem (1925) tested tetrachlorethane in the form of a jelly but found its toxicity to *Phylloxera* much inferior to that of carbon disulphide.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained 97% kill of the peach-tree borer (*Aegeria exitiosa*, Say) with 1 oz. of a mixture of tetrachlorethane (45%) and tobacco dust (55%), but the trees were sometimes killed.

COLEOPTERA.

Elateridae.

According to Parker (1928), tetrachlorethane appeared to be toxic to wireworms and other soil insects in laboratory tests.

Cerambycidae.

In an anonymous publication (New Mexico 1935), it is stated that 70% kill of larvae of *Prionus californicus*, Motsch., caged in artificial shelters, was obtained with an emulsion consisting of 1 oz. tetrachlorethane and 2 oz. soap to 1 U.S. gal. water per cu. ft.

DIPTERA.

Psilidae and Anthomyiidae.

K. M. Smith (1925) tested tetrachlorethane (5%) absorbed in chalk (95%) to control carrot fly (*Psila rosae*, F.) and the cabbage and onion root maggots (*Hylemyia brassicae*, Bch., and *H. antiqua*, Mg.), but in no case was there any significant improvement over the control plots.

Trypetidae.

Thiem (1935) obtained 99–100% kills of pupae of the cherry fruit-fly (*Rhagoletis cerasi*, L.) with 1, 2 and 3% emulsions consisting of 100 cc. tetrachlorethane, 25 cc. oil soap containing spirits, to 10 litres water. The emulsion was applied at 8–10 l./sq. m. (approximately 150 gm./sq. m.). This mixture was particularly useful for disinfesting areas from which the wild host plants had been removed, as it was liable to injure trees with which it came in contact.

MISCELLANEOUS.

See Marchal (1931) under Benzene (p. 74).

Thiocarbonates (see Sulphocarbonates, p. 132).

Thiocyanates (Rhodanates).

The thiocyanates are salts of thiocyanic acid, H.CNS, and the organic thiocyanates have come into prominence of recent years as contact insecticides, being especially useful as ovicides for incorporation in winter washes for fruit trees.

COLEOPTERA.

Scarabaeidae.

Bennett (1940) obtained 50% kill of larvae of the garden chafer (*Phyllopertha horticola*, L.) in artificially infested plots by watering with a 1·28% solution of dodecyl thiocyanate. He obtained 50 and 80% kill, respectively, with 1 and 2% emulsions of butyl carbitol thiocyanate (β-butoxy–β'-thiocyanodiethyl ether), but severe injury was caused to the treated grass. The mortality in the check plots was 5%.

Elateridae.

Miles and Cohen (1939) tested emulsions of the following organic thiocyanates as soil insecticides for wireworms (*Agriotes* sp.) in laboratory experiments.

Ethyl Thiocyanate. At 2 gals./sq. yd. of a 2·1% emulsion (114 cc./sq. m.), 85% kill was obtained after 6 days.

Butyl Thiocyanate. At 2 gals./sq. yd. of a 2·1% emulsion (114 cc./sq. m.), only 30% kill was obtained after 4 days.

"*Lethane* 410" (a mixture of 75% butyl carbitol thiocyanate and 25% kerosene). At 1 gal./sq. yd. of 33% emulsion (1,820 cc./sq. m.) all the wireworms were dead within 10 days.

An aliphatic Thiocyanate (S.W.9). 1·1% emulsion gave no control after 9 days.

Benzyl Thiocyanate. At 2 gal./sq. yd. a 2·1% emulsion (114 cc./sq. m.) gave 70% kill within 5 days. As in most cases the percentage kill materially increased after a period of time, the authors thought it was possible that breakdown products were responsible for the later kills.

Thus it would appear that the thiocyanates are not likely to be suitable for the control of wireworms except at non-economic rates.

Curculionidae.

English and Graham (1938) found the immersion of soil balls for 15 minutes in solutions of proprietary thiocyanates (Lethane 410 and Lorol) did not give effective control of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.).

HYMENOPTERA.

Formicidae.

Walker and Anderson (1937) found 1/200 dilution of a thiocyanate gave fairly good control of the pavement ant (*Tetramorium caespitum*, L.) attacking egg-plants, but reinfestation occurred after two weeks.

Thymol (Methyl Iso-Propyl Phenol) ($CH_3C_6H_3(OH)C_3H_7$).

Crystalline.

Experiments in Air.

Fleming (1925): minimum lethal dose 44 mg./l.

Experiments in Soil.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) obtained 90–100% kill of *Popillia japonica*, Newm., larvae when a saturated solution of thymol was poured over the soil about the roots of infested plants, though the treatment checked the plants considerably. Leach and Thomson (1921) had previously reported poor results in similar experiments.

ISOPODA.

Speyer and Owen (1924) found soil mixed with thymol in the proportion of 1 : 166 was toxic to the cucumber house woodlouse (*Armadillidium speyeri*, Jackson) after an exposure of 3 days, and remained effective for a further six.

Tobacco Extracts and Dusts (see also Nicotine, p. 115).

Extracts.

HEMIPTERA.

Coccidae.

Hargreaves (1924 *a*) controlled the coffee-root mealybug (probably *Pseudococcus kenyae*, Le Pelley) by tobacco-soap solution, but stated that it was only a temporary measure which it was necessary to repeat every 3 months.

Aphidae.

Girardi (1916) advised the use of a 1% tobacco extract with potash soap as a remedy for root Aphids. Malenotti (1922) experimented with a 4% tobacco extract mixed with kerosene to control the black peach aphis (*Anuraphis persicae-niger*, Smith) on the roots of peach trees. He did not obtain very satisfactory results, though they were somewhat improved by exposing the roots before treatment.

COLEOPTERA.

Scarabaeidae.

Cotton (1918) reported that a decoction of 8 oz. cured tobacco in 3 U.S. gals. water applied to sugar-cane stools in 1 U.S. pint doses had no effect on white grubs (*Lachnosterna* sp.) in Porto Rico. Decoppet (1920) stated that a 2% dilution of tobacco juice applied to the soil at 20 l./sq. m. (400 cc./sq. m.) had a marked effect on larvae of the cockchafer (*Melolontha melolontha*, L.), but not sufficient to be of economic value.

DIPTERA.

Tipulidae.

Mishchenko (1936) obtained 87–98% kill of larvae of *Tipula conjugata*, Alex., attacking rice with 4 oz. tobacco extract in 25 gallons of water.

Anthomyiidae.

Krasnyuk (1931) found tobacco extract useless as a control measure for the cabbage root maggot (*Hylemyia brassicae*, Bch.).

Dusts.

Tobacco dust, as the name implies, is a ground product of the dried leaves, or sometimes stalks and midribs, of the tobacco plant. The stalks contain about one-fourth the amount of nicotine as the leaves. Some years ago these dusts were sold with a guaranteed nicotine content, but now they are largely replaced by nicotine dusts.

THYSANOPTERA.

Richardson and Nelson (1933) found one pound of dust applied to 50 gladiolus corms the day after planting was useless for the control of the gladiolus thrips (*Taeniothrips gladioli*, Mlt. & Stwn.).

HEMIPTERA.

Aphidae.

Stedman (1896) stated that $2\frac{1}{2}$ to 5 lb. of tobacco dust placed in a furrow 4 ins. (10 cm.) deep around apple trees would leach down through the soil to kill woolly aphis (*Eriosoma lanigerum*, Hsm.). Marcovitch (1934), however, found a dust made from tobacco stems was ineffective for this purpose. Cutright (1925) was unable to control white aster root aphis (*Prociphilus erigeronensis*, Thos.) with $\frac{1}{4}$ to $\frac{1}{2}$ lb. (7 to 14 gm.) per aster plant.

LEPIDOPTERA.

Aegeriidae.

Headlee and Ilg (1926) successfully controlled larvae of the raspberry crown borer (*Pennisetia marginata*, Harr.) with applications of 1 lb. of dust (containing 0·0197 lb. nicotine) per hill.

Noctuidae.

Hawley (1918) found one handful of dust per hill, or of a mixture of equal parts of tobacco dust and lime or sulphur per hill, all ineffective for the control of the hop-borer (*Hydroecia immanis*, Gn.), although the dust alone did appear to cause some reduction.

COLEOPTERA.

Chrysomelidae.

Webster (1899) found $\frac{1}{2}$ to 4 lb. ($\frac{1}{4}$ to 2 kg.) ineffective for the control of the grape root worm (*Fidia viticida*, Walsh). Weigel and Doucette (1922) also obtained negative results in the control of the strawberry root worm (*Paria canella*, F.) attacking roses with applications of one handful of dust per plant.

DIPTERA.

Anthomyiidae.

Eyer (1922) for the control of the onion maggot (*Hylemyia antiqua*, Mg.), and Krasnyuk (1931) for the cabbage root maggot (*H. brassicae*, Bch.), both found tobacco dust useless. O'Kane (1922 *b*) also obtained inconclusive results in the control of cabbage root maggots with a mixture of equal parts of finely ground tobacco dust and limestone, although this mixture had killed eggs in contact with it.

MYRIOPODA.

Cory and O'Neill (1917) obtained 85% kill of millepedes (*Orthomorpha gracilis*, Koch) near the surface of the soil with applications of 1 oz./sq. ft. (34 gm./sq. m.), but only 5% kill of the deeper millepedes. A second application was given 3 days later, and only 5% of the total number of millepedes remained at the end of the week. McLeod and Butcher (1934) did not obtain satisfactory control of the millepede, *Cylindroiulus londinensis coeruleocinctus*, Wood (and also of *Sciara* sp.—Diptera), attacking potatoes with 400 to 500 lb./ac. (45 to 56 gm./sq. m.).

The Addition of other Substances to Tobacco Dust.

Brittain (1920, 1921, 1922) used tobacco dust as a diluent and carrier for lime-sulphur (p. 108), white arsenic (p. 71), and corrosive sublimate (p. 105).

Tolidine ($NH_2CH_3.C_6H_3.C_6H_3.CH_3NH_2$).

Crystalline.

Fleming (1928) found soil mixed with 0·66% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 3 weeks.

Toluene ($C_6H_5.CH_3$).

Liquid. S.G. 0·866 at 20° C.

Experiments in Air.

Tattersfield and Roberts (1920): of low toxicity (420); Fleming (1925): minimum lethal dose 248 mg./l.

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) found 2 cc. injected into the soil of a flower-pot killed the mealybug, *Rhizoecus terrestris*, Newst., without injuring Acacia plants.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained 48% kill of peach-tree borers with applications to peach trees of ½-oz. doses absorbed in sawdust.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) obtained 33% kill of *Popillia japonica*, Newm., larvae in soil watered with a saturated solution. Plants were checked by the treatment.

Staphylinidae.

Vincent (1916) obtained good results in the control of an unidentified Staphylinid causing damage to turnips in France with 100 l./ha. (9 gm./sq. m.) of toluene, but the treatment was very expensive.

p-Toluene Sulphonylchloride ($CH_3.C_6H_4.SO_2Cl$).

Experiments in Air.

Fleming (1925): non-toxic up to 796 mg./l.

Toluidine ($CH_3C_6H_4NH_2$).

o- and *m*-forms liquid; *p*-form crystalline.

Experiments in Air.

Tattersfield and Roberts (1920): both *o*- and *p*-forms highly toxic (8·5). Fleming (1925): *o*-, minimum lethal dose in air, 16 mg./l.; in water, 1,125 mg./l.; *p*-, minimum lethal dose in air, 8 mg./l.

Experiments in Soil.

LEPIDOPTERA.

Aegeriidae.

Peterson (1923 *a*) obtained 76% kill of the peach-tree borer (*Aegeria exitiosa*, Say) with a ½-oz. dose per tree. Despite its low rate of evaporation it was thus as toxic as *p*-dichlorbenzene.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% *p*-toluidine was toxic to larvae of *Popillia japonica*, Newm., for an exposure of one week.

o-Toluidine Hydrochloride ($CH_3C_6H_4NH_2HCl$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 1 week.

Trichloraniline ($C_6H_2Cl_3NH_2$).

Crystalline.

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 1 week.

Trichlorbenzene ($C_6H_3Cl_3$).

Liquid.

Experiments in Air.

Tattersfield and Roberts (1920) : 1 : 2 : 4 of uncertain toxicity.

Experiments in Soil.

ISOPTERA.

Hockenyos (1939) found soil mixed with 1 part in a 1,000 of trichlorbenzene was lethal to termites after an exposure of 39 hours.

Trichlorethylene ($CHCl : CCl_2$).

Liquid. S.G. 1·460 at 25° C.

Experiments in Air.

Tattersfield and Roberts (1920) : low toxicity (1200).

Experiments in Soil.

HEMIPTERA.

Coccidae.

Saunders (1926) found a miscible trichlorethylene watered on to the soil gave good control of the mealybug, *Rhizoecus terrestris*, Newst., without injuring Acacia plants.

COLEOPTERA.

Scarabaeidae.

Bell (1935) reported that it was less toxic to the sugar-cane grub (*Dermolepida albohirtum*, Waterh.) than carbon disulphide. Anderson (1931) obtained promising results in the control of larvae of the brown chafer (*Serica brunnea*, L.) with 12 injections per sq. yd., each of 5 gm. (72 gm./sq. m.).

Trihydroxybenzene (see Phloroglucinol, p. 123).

Trimethylamine ($(CH_3)_3N$).

Gas.

Experiments in Air.

Tattersfield and Roberts (1920) : moderately toxic (40).

2 : 4 : 6 Trinitrophenol (Picric Acid) ($HO . C_6H_2(NO_2)_3$).

Crystalline.

Experiments in Air.

Tattersfield and Roberts (1920) : non-toxic.

Turpentine.

Experiments in Water.

Leach and Thomson (1921) obtained 100% kills of *Popillia japonica*, Newm., larvae dipped for 2 hours in a 1% dilution, or for ½ hour in a 2% dilution, of an emulsion consisting of 4 cc. carbon disulphide, 4 cc. castor oil, 4 cc. turpentine, and 16 cc. soap solution.

Experiments in Soil.

COLEOPTERA.

Elateridae.

Zappe (1922) found a turpentine emulsion consisting of 4 oz. soap, 4 oz. turpentine in 1 U.S. quart water was of no value for controlling wireworms.

Curculionidae.

English and Graham (1938) obtained only low kills of larvae of the white-fringed beetle (*Pantomorus leucoloma*, Boh.) in soil balls when the latter were immersed for 15 minutes in a turpentine emulsion.

White Oil.

DIPTERA.

Syrphidae.

Wilcox (1927) tested a 4% emulsion of white oil as a control measure for the Narcissus bulb fly (*Merodon equestris*, F.) and the lesser bulb fly (*Eumerus strigatus*, Fall.). The liquid was poured around the bases of the plants at weekly intervals from April to the end of May; in both the treated and untreated rows 7% of the plants were infested by the first fly, but only 4% of the treated plants were attacked by the lesser bulb fly, compared with 35% in the checks.

Wood Ashes.

COLEOPTERA.

Chrysomelidae.

Weigel and Doucette (1922) found wood ashes of no value for the control of the strawberry root worm (*Paria canella*, F.) attacking roses.

DIPTERA.

Psilidae.

See Ironside (1921) under Kerosene.

Wood Oils.

These are derived from the destructive distillation of wood in a similar way to the production of coal-tar oils from coal.

Pine-Tar Creosote.

HEMIPTERA.

Aphidae.

Cory (1915) found a 6% emulsion (and, 1923 *a*, 5 and 8%) of pine-tar creosote poured into a trench dug to expose the roots of apple trees was effective in freeing them from woolly aphis (*Eriosoma lanigerum*, Hsm.). Marcovitch (1934) reported rather variable results with such emulsions for the same pest.

LEPIDOPTERA.

Aegeriidae.

See Cory (1928 *a*) under *p*-dichlorbenzene (p. 48).

COLEOPTERA.

Scarabaeidae.

Burns (1929) tested the effect of 10 and 20% solutions of pine-tar creosote in benzene to control *Dermolepida albohirtum*, Waterh., grubs attacking sugar-cane.

1/6 oz. doses applied 4 in. (10 cm.) deep on both sides of the stools with a Vermorel injector showed improved results compared with untreated cane. A 10% solution in carbon disulphide was not so effective.

Chrysomelidae.

Feytaud (1932) reported inconclusive results with pine-tar products in the control of Colorado beetles (*Leptinotarsa decemlineata*, Say).

Other Wood Oils.

COLEOPTERA.

Curculionidae.

F. F. Smith (1932) found beech wood creosote of no value as a soil fumigant for larvae of the vine weevil (*Otiorrhynchus sulcatus*, F.).

DIPTERA.

Anthomyiidae.

Brittain (1921) found a mixture of wood creosote (2%) and clay (98%) applied to brassicas resulted in a decrease of the percentage of plants attacked by the cabbage root maggot (*Hylemyia brassicae*, Bch.), from 27–39 in the controls to 1·78 in the treated plots.

Wormseed Oil.

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) obtained 100% kill of *Popillia japonica*, Newm., larvae in soil treated with a saturated solution of wormseed oil; plants growing in the soil were checked slightly. They also tested the various constituents separately and found the order of toxicity to be: ascaridoles, terpenes, and residue (ascaridole glycol). Fleming (1928) found wormseed oil more toxic to the larvae in water than carbon disulphide.

Xylene (Xylol) ($C_6H_4(CH_3)_2$).

m- liquid, S.G. 0·8·66; *p*- crystalline, M.P. 15° C.

Experiments in Air.

Tattersfield and Roberts (1920): *m*- and *p*-forms both of low toxicity (230). Fleming (1925): minimum lethal dose 248 mg./l.

Xylidene (Dimethyl Aminobenzene) ($(CH_3)_2C_6H_3 . NH_2$).

Liquid.

Experiments in Air.

Tattersfield and Roberts (1920): highly toxic, but with a tendency to be uncertain (8·5).

2 : 4-Xylidene Hydrochloride ($(CH_3)_2C_6H_3NH_2HCl$).

COLEOPTERA.

Scarabaeidae.

Fleming (1928) found soil mixed with 0·16% was toxic to larvae of *Popillia japonica*, Newm., for an exposure of 1 week.

Zinc Chloride ($ZnCl_2$).

COLEOPTERA.

Scarabaeidae.

Leach and Johnson (1925) reported that a 5% solution watered on to the soil failed to kill larvae of *Popillia japonica*, Newm., but killed plants growing in the soil.

For other Zinc Salts (see Arsenates, p. 72, Borates, p. 75, Fluorides, p. 95).

Zinc Ammonium Salts (see Fluorides, p. 95).

APPENDICES.

Appendix 1.

Tattersfield and Roberts (1920). (For details, see p. 4.)

Vapours toxic to Wireworms.

Toxicity measured in millionths of a gm. mol. per 1,000 cc. of air found toxic in 1,000 mts. at 15° C.

The first figure represents the death point and the second the recovery point.

Of High Toxicity (1–10)		*Of Moderate Toxicity* (10–100)	
Allyl isothiocyanate	0·75—0·4	Hydrocyanic acid	20—15
Chloropicrin	2—1	*o*-Chloraniline	19·0
Dichlorphenol (1 : 2 : 4)	1·8	Benzal chloride	24
Monomethylaniline	3·7—2·0	Ammonia	23—18
Benzyl chloride	4—3·5	Monomethylamine	24—16
o-Chlorphenol	6—4	Ethylamine	22—17
p-Chlorphenol	6—4	Dimethylamine	22—16
o-Nitrophenol	6—5	Nitrobenzene	24—16
Dimethylaniline	6·6—5	Aniline	27—21·5
Xylidine (but with a tendency to be uncertain)	7 —5	Trimethylamine	40—32
		Iodobenzene (incap.) *	50—25
o-Toluidine	8·5—6·5	Amyl nitrite	64—60
p-Toluidine	8·5—6·5	*o*-Dichlorbenzene	70—50
o-Cresol	9 —7·4	Pyridine	76—60
m-Cresol	9 —7·4	Pseudocumene	95—80
p-Cresol	9 —7·4	Bromoform	94
Phenol	10·6—10	Monobrombenzene	96—80

Of Low Toxicity (100–20,000)		*Marginal and uncertain*	*Non-toxic*
Monochlortoluene	120—80	*o*-Nitro-Cl-benzene	Anthracene
Tetrachlorethane	141—60	*o*-Nitrotoluene	Phenanthrene
Amyl nitrate	180—140	*p*-Nitrotoluene	Iodoform
Monochlorbenzene	200—170	Nitroxylene	Nitrobenzaldehyde
Xylene (*p*)	230—190	Naphthalene	Dinitrobenzene
Xylene (*m*)	230—185	*p*-Nitraniline	Nitronaphthalene
Toluene	420—350	*p*-Dichlorbenzene	*p*-Nitrophenol
Carbon disulphide	526—400	Trichlorbenzene	*o*- and *m*-Nitraniline
Nitromethane	710	(1 : 2 : 4).	Trinitrophenol (Picric acid)
Benzene	775—650	*p*-Chloraniline	Metaphenylene diamine
Heptane	800	*p*-Nitro-Cl-benzene	Phenyl hydrazine
Chloroform	1,040—800	Mesitylene	Naphthylamine
Carbon tetrachloride	1,600	*p*-Cymene	Diphenylamine
Trichlorethylene	1,200	Benzotrichloride	
Hexane	3,000	Monochlorxylene	
Dichlorethylene	3,100—2,400		
Pentane (incap.)*	16,600		

* The higher concentration incapacitates.

Appendix 1 (*con.*).—**Fleming (1925).**

The toxicity of various organic compounds to third-instar larvae of the Japanese beetle, *Popillia japonica*, Newm.

The minimum lethal dose is expressed as the number of milligrams per litre (mg./l.) for a 24-hours exposure at 26·7° C. The figures in brackets are the amounts required to kill the larvae in water.

Benzyl chloride	4 (36)
Phenol	4 (592)
o-Cresol	8 (625)
Naphthalene	8 (150)
p-Toluidine	8
Nicotine	16
o-Toluidine	16 (1,125)
p-Dichlorbenzene	22 (332)
Sodium cyanide	8 (150)
Calcium cyanide	16
Nitrobenzene	22 (800)
Aniline	22 (1,020)
Thymol	44
o-Nitro-toluene	44 (582)
Furfural	44
Hexachlorethane	124 (157)
Brombenzene	90 (247)
Carbon disulphide	44 (215)
m-Cymene	90 (1,000)
Chlorbenzene	124 (366)
Formaldehyde	44
Acetone	90
Pyridine	124
Methyl ethyl ketone	124
Paraldehyde	248
Benzylamine	248
m-Xylene	248
p-Nitro-chlorbenzene	796
Toluene	248
Carbon tetrachloride	796
Chloroform	796
Dichlorethylene	796
Ether	796

Non-toxic (larvae not killed at 796mg./l.):
Calcium cyanamide
o-Nitro-chlorbenzene
Diphenyl
α-Naphthol
β-Naphthol
m-Dinitrobenzene
1, 5-Dinitronaphthalene
Anthracene
p-Toluene sulphonylchloride
Sodium benzene sulphonate
Sodium *p*-toluene sulphonate

Appendix 2.—Conversion Tables.

(Only correct to the third place.)

LINEAR. 1 m.=1·094 yds.=39·37 in. 1 yd.=0·914 m.

SQUARE. 1 sq. m.=1·19 sq. yds.=10·76 sq. ft.
1 acre=10 sq. chains=4,840 sq. yds.=0·450 ha. (Hectare).
1 rod=30¼ sq. yds.
1 hectare (ha.)=10,000 sq. m.=2·47 ac.=11,959 sq. yds.

VOLUME. 1 imp. gallon=4·55 litres=1·2 U.S. gal.
1 U.S. gallon=3·792 litres=0·83 imp. gal.
1 imp. pint=568 cc., 1 U.S. pint=474 cc.
1 imp. quart=1,136 cc., 1 U.S. quart=948 cc.
1 litre=2·11 U.S. pints=1·76 imp. pints.
1 fl. oz.=28 cc., 1 imp. pint=20 fl. oz.
1 cu. ft.=0·0283 cu. m.

WEIGHT. 1 oz.=28·3 gm., 1 lb.=453·5 gm.
1 metric quintal (Qx)=1 Doppelzentner (Dz.)=100 kg.=220·46 lb.
1 U.S. cwt.=100 lb., 1 imp. cwt.=112 lb.
1 U.S. ton=2,000 lb., 1 imp. ton=2,240 lb.

RATES. 1 cwt./ac.=1·256 dz./ha.=12·6 gm./sq. m.
1 dz./ha.=10 gm./sq. m.=0·796 cwt./ac.=90 lb./ac.
1 kg./ha.=0·892 lb./ac.=0·1 gm./sq. m.
1 lb./ac.=0·112 gm./sq. m.
1 oz./sq. ft.=305 gm./sq. m., 1 oz./sq. yd.=34 gm./sq. m.
1 lb./1,000 sq. ft.=4·88 gm./sq. m.
1 oz./U.S. gal.=7·4 gm./l., 1 oz./imp. gal.=6·2 gm./l.
1 lb./cu. yd.=600 gm./cu. m.

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[Where a second reference in brackets (*e.g.* R.A.E., A **12**, 561) follows the original reference, it implies that an abstract has been relied upon in the main. Where possible, original papers were consulted for tables and figures, even if the present writer was unfamiliar with the language concerned.

To avoid an unwieldy number of anonymous references the majority of these have been referred to the experiment station or place of origin, *e. g.* the text-reference *Anon. Barbados* 1914 would be found under Barbados.]

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Printed by TAYLOR & FRANCIS, LTD., Red Lion Court, Fleet Street, E.C. 4.